OR for policy evaluation: Evaluating public transport by multimodal schedule-based routing

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Joint works:

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EWG-POR **Online seminar, Sep. 9th, 2022**

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Team



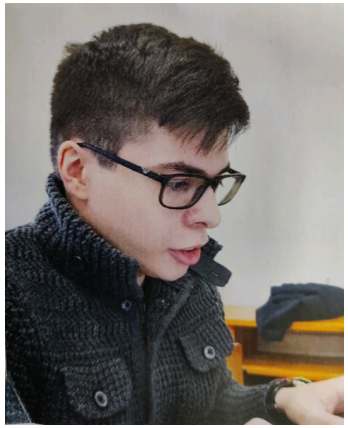
Juan Nicolas Ibanez, JRC



Martina Fischetti, JRC



Davide Duma, UniPv



Claudio Tomasi, UniPv

Section 1

1 Introduction

2 The JRC case

3 Multimodal routing

4 VelociRAPTOR

5 Ongoing work

Outline

1. Introduction on Multimodal Transport
   - The user perspective
   - The policy maker perspective
2. Evaluating Public Transit at National Level (the JRC case)

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   - The user perspective
   - The policy maker perspective
2. Evaluating Public Transit at National Level (the JRC case)
3. Multimodal routing algorithms: Models and algorithms
4. Our solution: VelociRAPTOR
   - Overview
   - Computational results
5. Conclusions

Motivations for promoting Public Transit

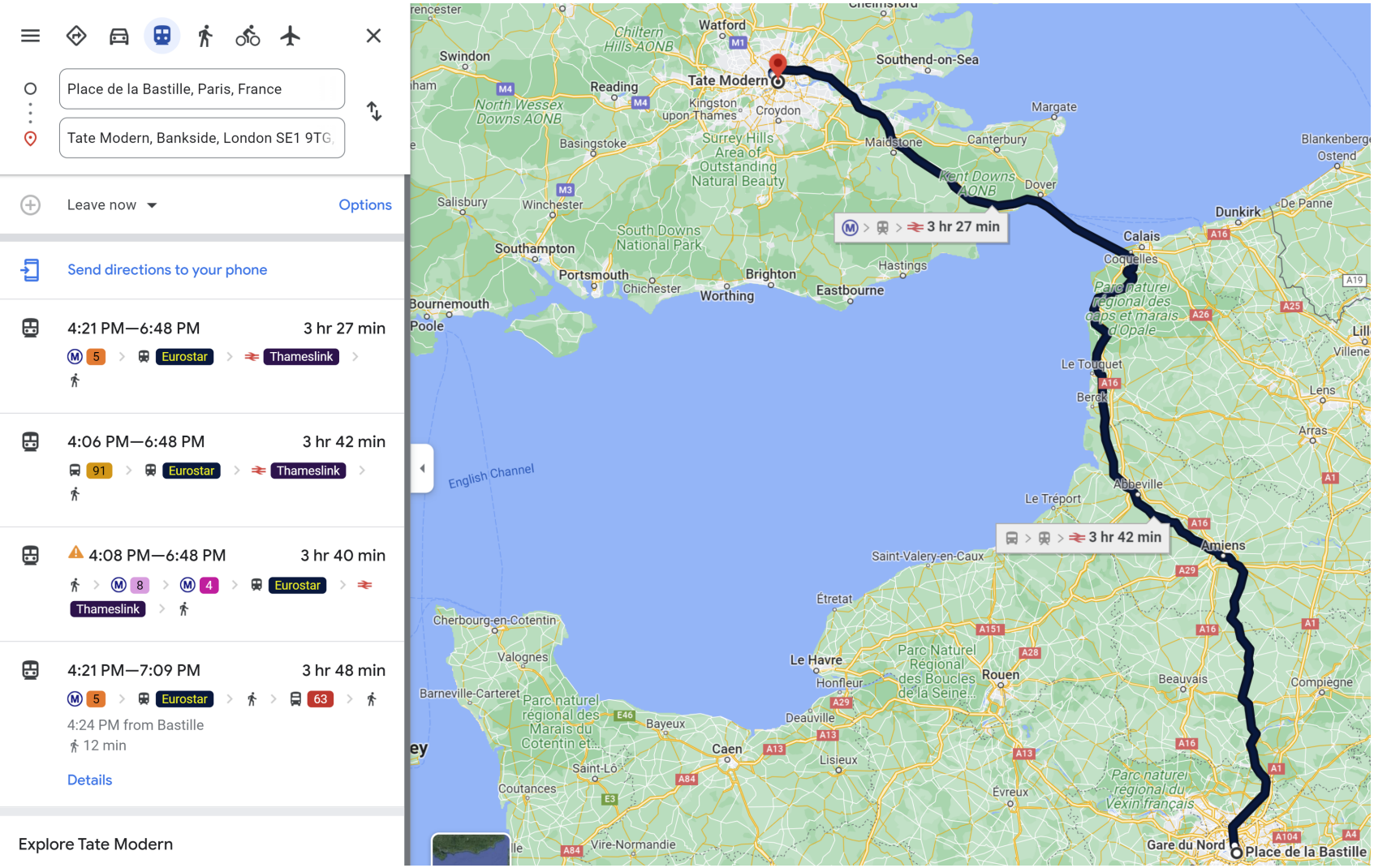
Public Transit Systems provide access to **opportunities** *[CS19]*

Motivations for promoting Public Transit

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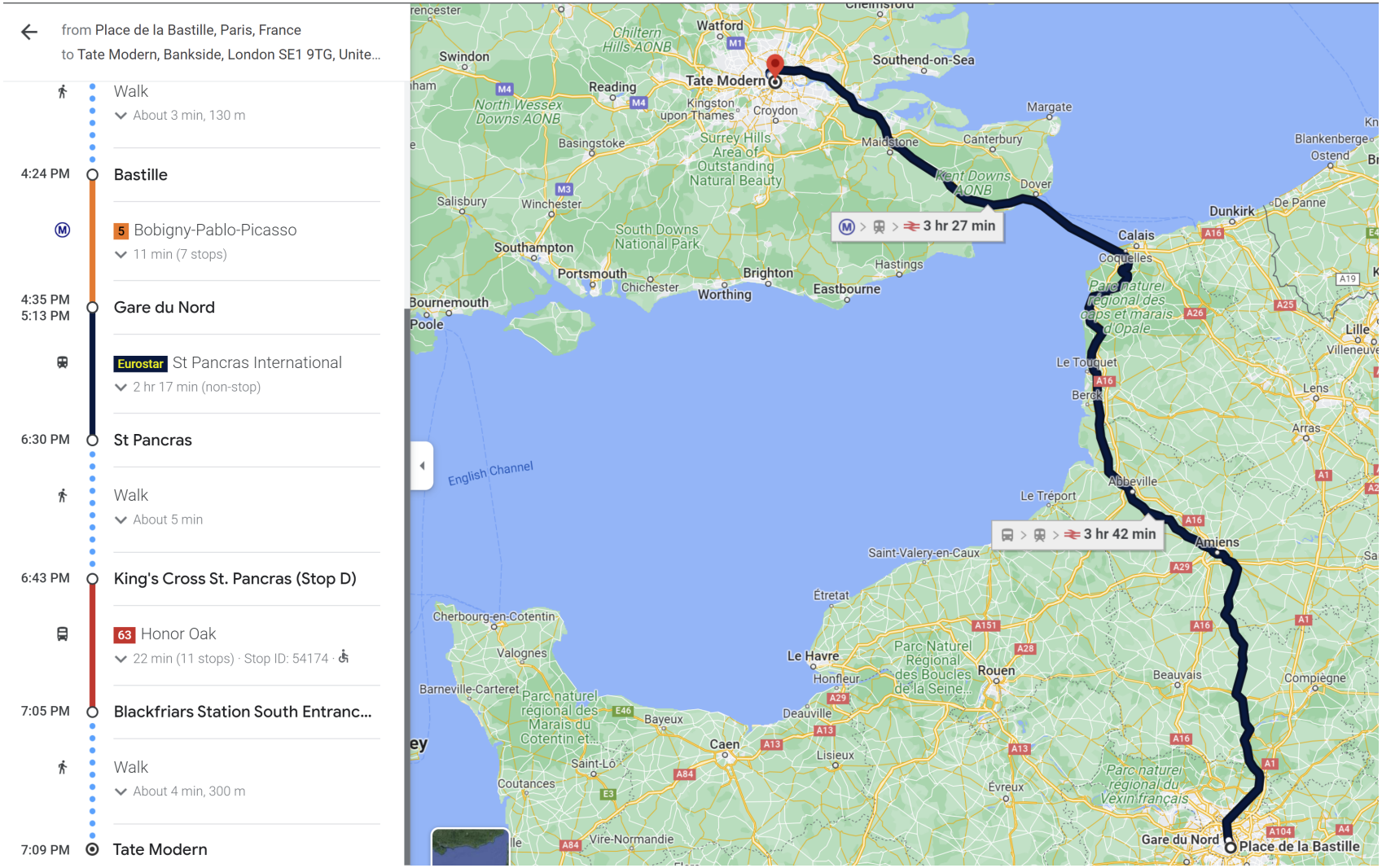
Decarbonising Europe's transport sector: *Passenger and freight transport generate around a quarter of Europe's total carbon emissions.*

The user perspective: Point-to-Point (shortest?) paths



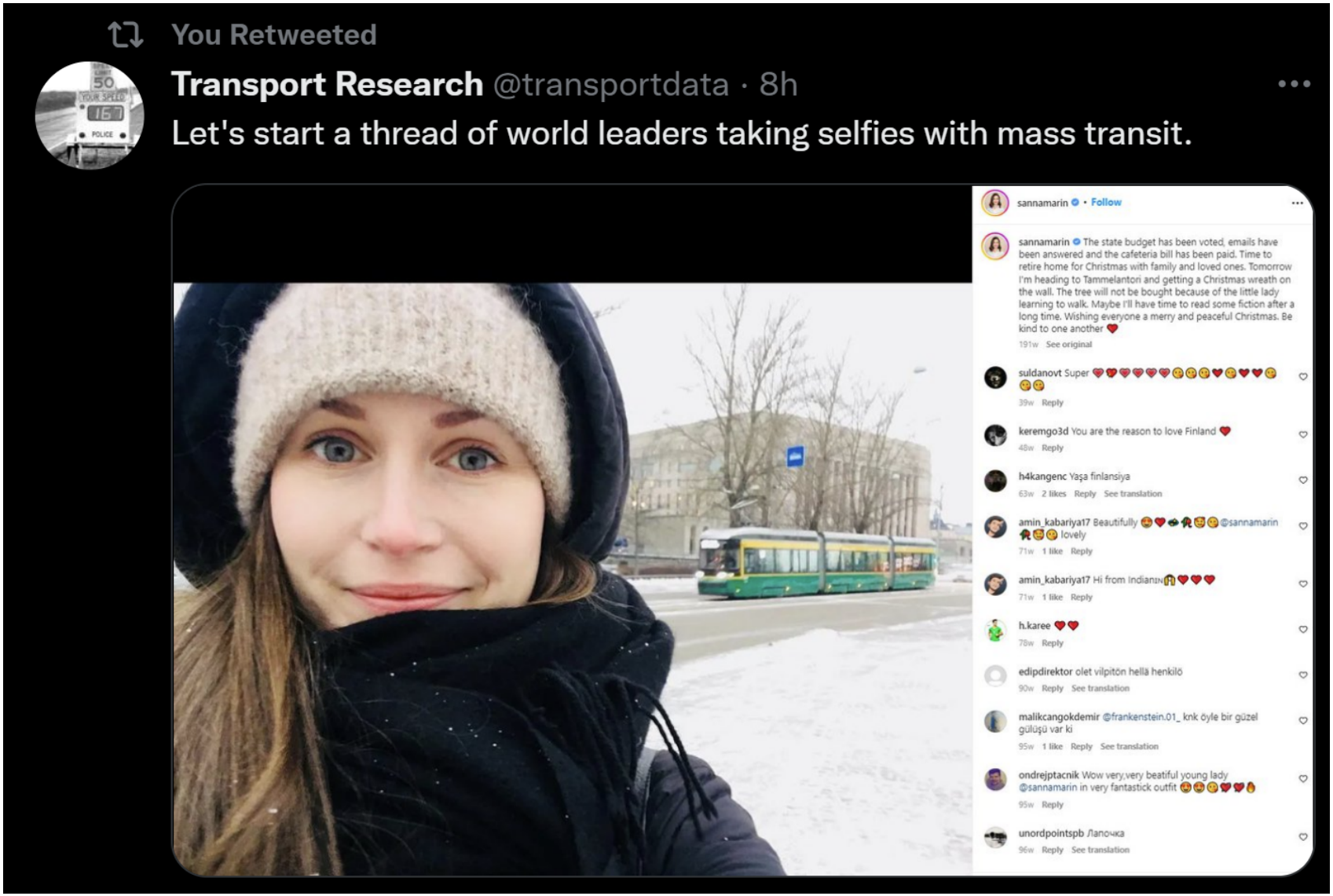
REMARK: We get a set of Pareto Optimal time-dependent paths

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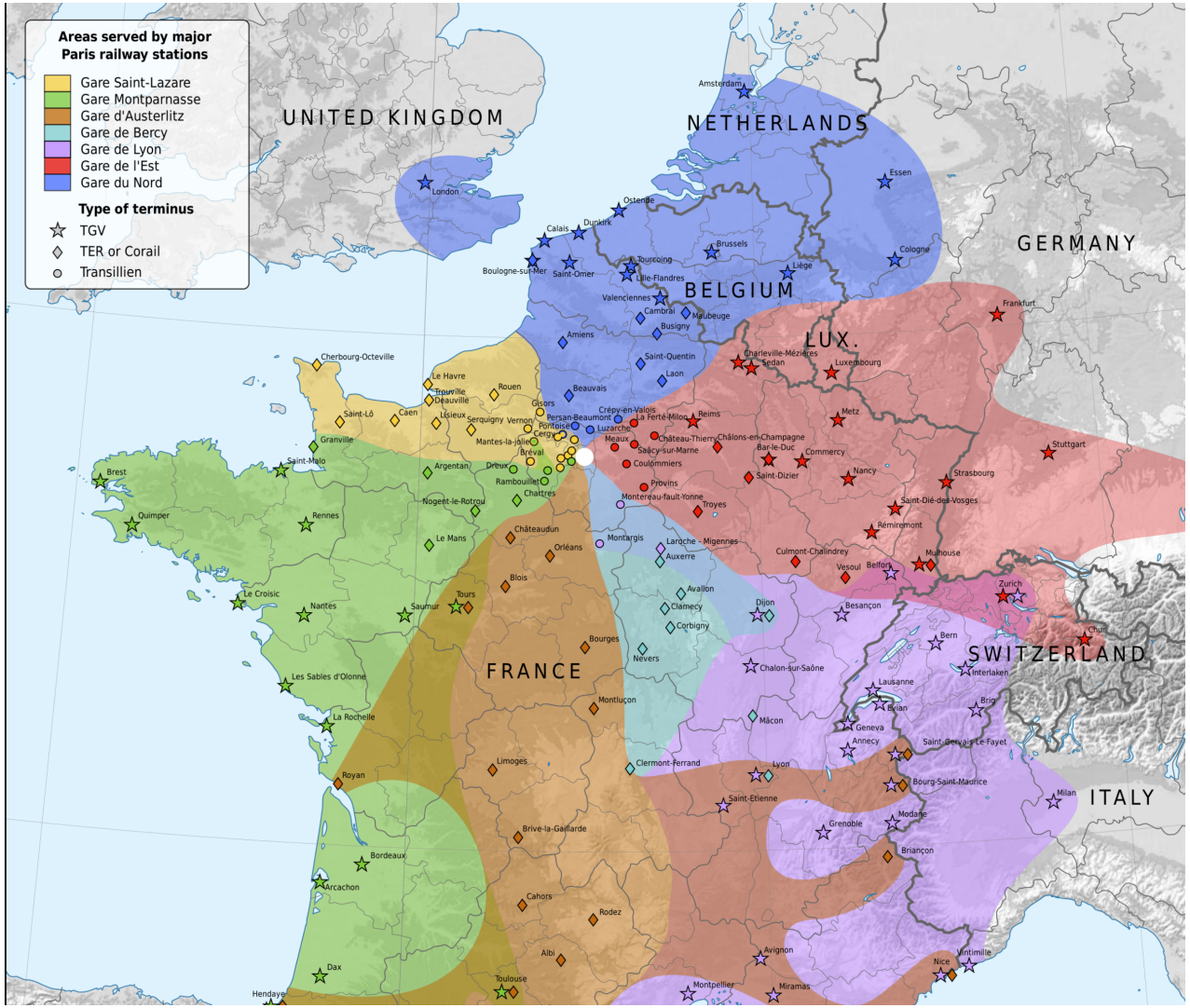


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The policy maker perspective



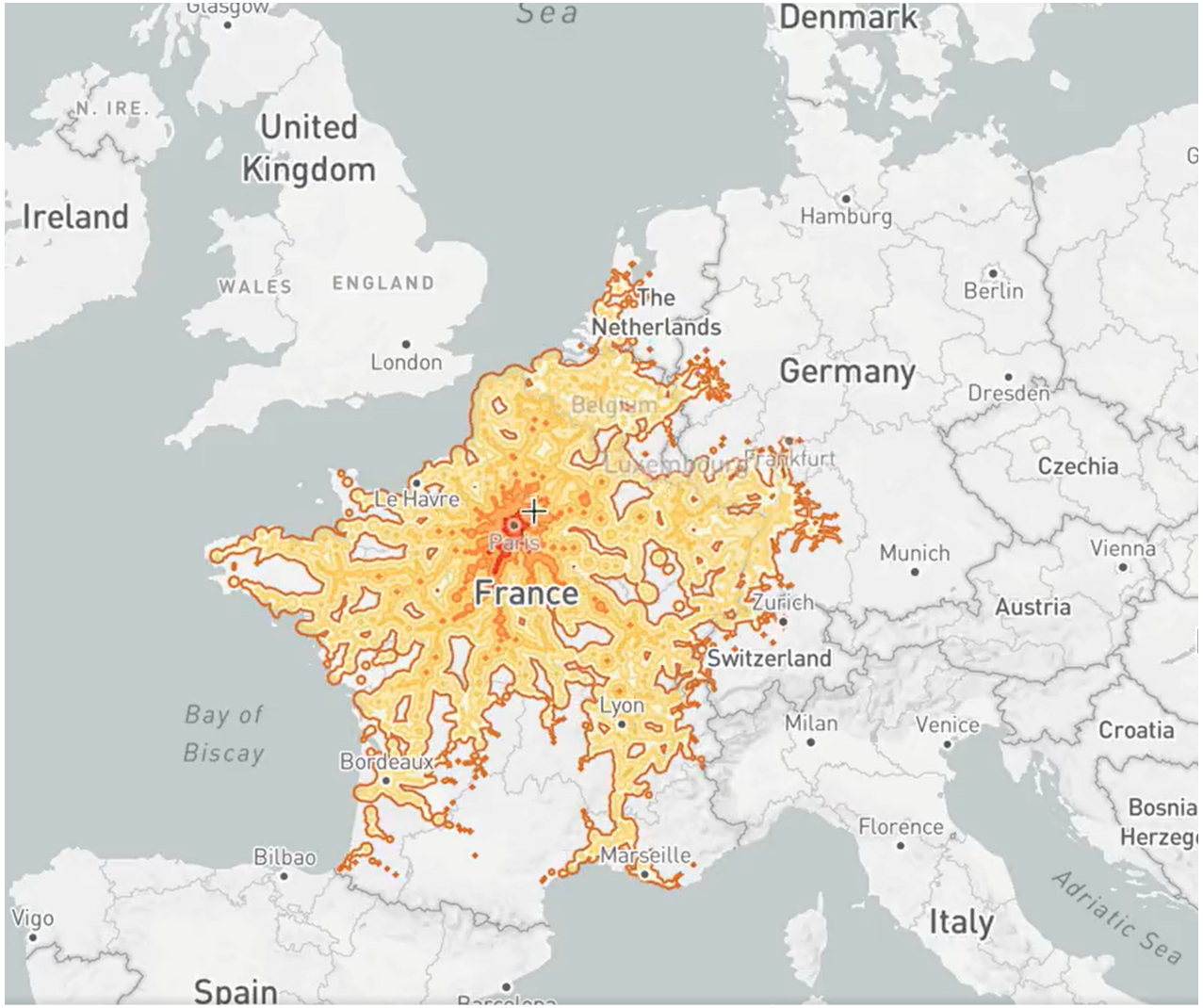
The policy maker perspective: One-to-All paths



REMARK: The policy maker analyzes where we can go from a given origin

5 hours train ride: One-to-All constrained paths

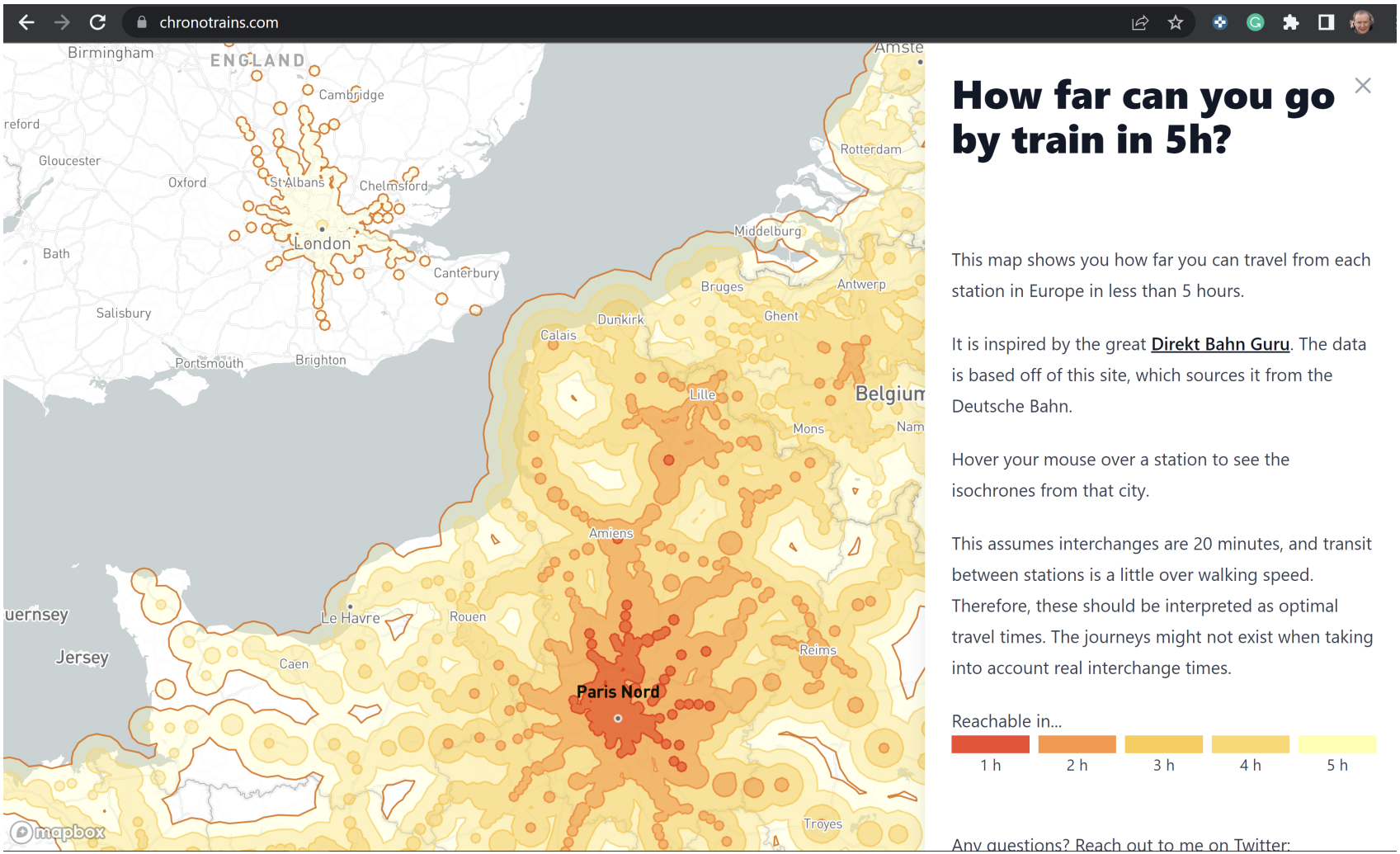
https://www.chronotrains.com/



REMARK: The policy maker analyzes how far we go by train

5 hours train ride: One-to-All constrained paths

https://www.chronotrains.com/



REMARK: The webapp is not considering buses and metro between train stations

Section 2

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Credits: Martina Fischetti and Nicolas Ibanez @ JRC



Policy makers

Directorates want to better understand the current situation and the impact of possible future policies

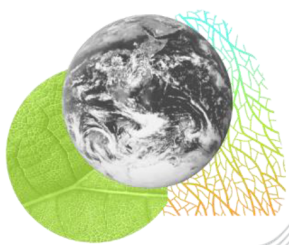
Joint Research Center (JRC)

Science and knowledge service

Climate neutrality in 2050 (European green deal)







JRC Directorate C - Energy, Transport and Climate

European Commission

Credits: Martina Fischetti and Nicolas Ibanez @ JRC

Example of analyses in the JRC transport group



Credits: Martina Fischetti and Nicolas Ibanez @ JRC

Public transport: Accessibility to opportunities in the different countries



Policy makers

want to have a **measure** of accessibility across Europe and **compare** public transport performances

Joint Research Center (JRC)

We developed (OR-based) tools to support

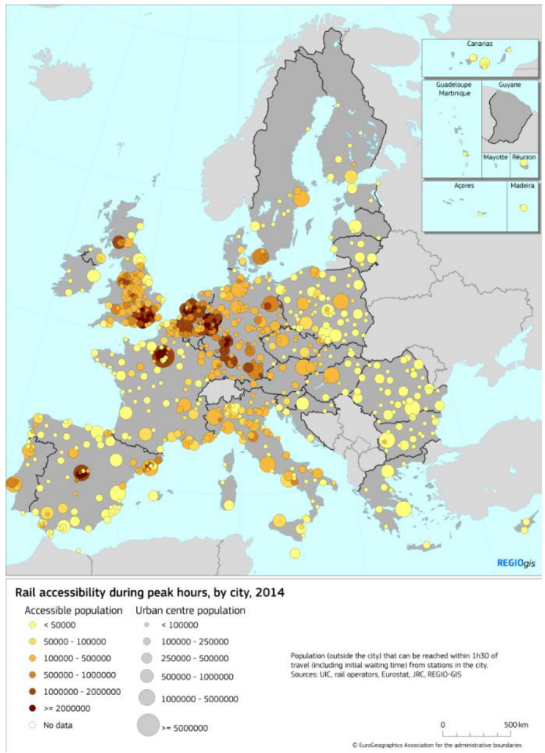
- **To better understand the current situation**
- **To anticipate future needs**
- **To promote fairness/ suggest actions**

European Commission

Credits: Martina Fischetti and Nicolas Ibanez @ JRC

Public transport: Accessibility to opportunities in the different countries

Accessibility **(in simple words): how many opportunities one can reach in a certain time (e.g. 2h) with a maximum number of transfers (e.g. 2) using public transport.**



Credits: Martina Fischetti and Nicolas Ibanez @ JRC

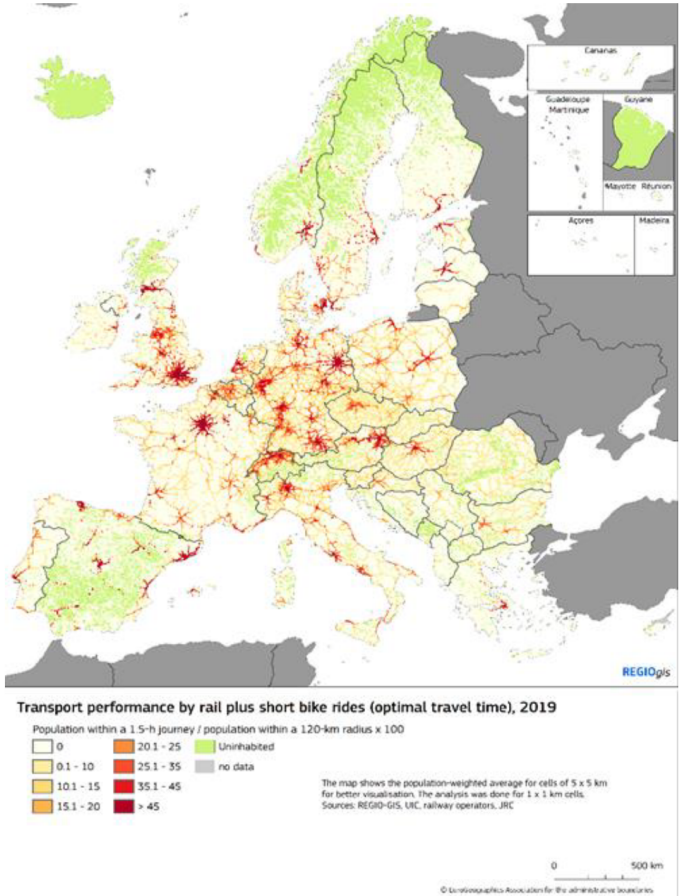
Accessibility as access to opportunities

In this analysis we estimate **opportunities by population**

-> Accessibility now measures the number of people that can be reached (through public transport)

Credits: Martina Fischetti and Nicolas Ibanez @ JRC

So far solved for trains



European Commission, Directorate-General for Regional and Urban Policy,
Brons, Martijn ; Poelman, Hugo ; Ackermans, Linde ; Ibáñez, Juan Nicolás ; Dijkstra, Lewis
Passenger rail performance in Europe : regional and territorial accessibility indicators for passenger rail, 2022

The challenge: Moving to Trains to Multimodal Transport

VIDEO CLIP OF ESTONIA

The challenge: Moving to Trains to Multimodal Transport

QUESTION: Why is the challenge so difficult?

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		Estonia	Netherlands	Switzerland
Stops	Train	238	1 214	6 018

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SHORT ANSWER: Because of runtime and memory issues

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O.R. is the enabling technology for accessibility analysis

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Multimodal schedule-based routing

Definition 1 (Timetable)

A **timetable** is defined by a tuple $(\Pi, \mathcal{S}, \mathcal{T}, \mathcal{R}, \mathcal{F})$, where

- $\Pi \subset \mathbb{N}_0$ is the **period of operation** (in minutes)
- $\mathcal{S}$ is the set of **stops**
- $\mathcal{T}$ is the set of **trips**, that is, a sequence of pairs (*Stop*, *TimeStamp*)
- $\mathcal{R}$ is the set of **routes**. A route consists of trips that share the exact same sequence of stops
- $\mathcal{F}$ is the set of **transfers**, which are not schedule-based

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In practice, given in the GTFS format.

Reference: `https://gtfs.org/schedule/reference`

Example: 3 routes and 26 trips

Autoguidovie

Orario valido dal 09/06/2022

Linea 7 **CURA C. > Q.re Vallone - Pastrengo > Ist. Maugeri - Mondino**

LUNEDI`-VENERDI` - ESTIVO

CURA C.	Poma, 5				06.45	07.11	07.31		08.15			09.16						11.16						13.15			14.15
CURA C.	Dosso/De Gasperi				06.45	07.11	07.31		08.15			09.16						11.16						13.15			14.15
CURA C.	Dosso/Della Spiga				06.45	07.11	07.31		08.15			09.16						11.16						13.15			14.15
CURA C.	Prado - Della Paiola/Art.				06.51	07.17	07.37		08.21			09.21						11.21						13.20			14.20
PAVIA	Della Paiola/Ferrari				06.55	07.21	07.42		08.26			09.25						11.25						13.24			14.24
PAVIA	Vallone - Pastrengo	06.02	06.19	06.38				08.00		08.45	09.05		09.43	10.01	10.22	10.43	11.04		11.44	12.01	12.21	12.41	13.01		13.43	14.03	
PAVIA	Pensa/Maciachini	06.03	06.20	06.39	06.56	07.22	07.43	08.01	08.27	08.46	09.06	09.26	09.44	10.02	10.23	10.44	11.05	11.26	11.45	12.02	12.22	12.42	13.02	13.25	13.44	14.04	14.25
PAVIA	Pensa/Bologna	06.03	06.20	06.39	06.57	07.23	07.44	08.02	08.28	08.46	09.06	09.27	09.44	10.02	10.23	10.44	11.05	11.27	11.45	12.02	12.22	12.42	13.02	13.26	13.44	14.04	14.26
PAVIA	Tavazzani/Lardirago	06.05	06.22	06.41	06.58	07.24	07.45	08.04	08.29	08.48	09.08	09.28	09.46	10.04	10.25	10.46	11.07	11.28	11.47	12.04	12.24	12.44	13.04	13.27	13.46	14.06	14.27
PAVIA	Tavazzani/Brusoni	06.05	06.22	06.41	06.58	07.24	07.45	08.04	08.29	08.48	09.08	09.28	09.46	10.04	10.25	10.46	11.07	11.28	11.47	12.04	12.24	12.44	13.04	13.27	13.46	14.06	14.27
PAVIA	Ceva, 16	06.06	06.23	06.42	06.59	07.25	07.46	08.05	08.30	08.49	09.09	09.29	09.47	10.05	10.26	10.47	11.08	11.29	11.48	12.05	12.25	12.45	13.05	13.28	13.47	14.07	14.28
PAVIA	Ceva/Marchesi	06.06	06.23	06.42	06.59	07.25	07.46	08.05	08.30	08.49	09.09	09.29	09.47	10.05	10.26	10.47	11.08	11.29	11.48	12.05	12.25	12.45	13.05	13.28	13.47	14.07	14.28
PAVIA	Treves/Ortaglia Ospedale	06.07	06.24	06.43	07.00	07.26	07.47	08.06	08.31	08.50	09.10	09.30	09.48	10.06	10.27	10.48	11.09	11.30	11.49	12.06	12.26	12.46	13.06	13.29	13.48	14.08	14.29
PAVIA	Treves/Vigentina	06.08	06.25	06.44	07.01	07.27	07.48	08.07	08.32	08.51	09.11	09.31	09.49	10.07	10.28	10.49	11.10	11.31	11.50	12.07	12.27	12.47	13.07	13.30	13.49	14.09	14.30
PAVIA	Vigentina, 17 (Parco)	06.09	06.26	06.45	07.02	07.28	07.49	08.08	08.33	08.52	09.12	09.32	09.50	10.08	10.29	10.50	11.11	11.32	11.51	12.08	12.28	12.48	13.08	13.31	13.50	14.10	14.31
PAVIA	Tasso/Della Torretta	06.10	06.27	06.46	07.04	07.30	07.51	08.10	08.35	08.54	09.14	09.34	09.52	10.10	10.31	10.52	11.13	11.34	11.53	12.10	12.30	12.50	13.09	13.32	13.51	14.11	14.33
PAVIA	Tasso/Bona di Savoia	06.11	06.28	06.47	07.04	07.31	07.52	08.11	08.36	08.54	09.14	09.34	09.52	10.10	10.31	10.52	11.13	11.34	11.53	12.10	12.30	12.50	13.10	13.33	13.52	14.12	14.33
PAVIA	Tasso/Alzaia/Colesino	06.12	06.29	06.48	07.06	07.33	07.54	08.13	08.38	08.56	09.16	09.36	09.54	10.12	10.33	10.54	11.15	11.36	11.55	12.12	12.32	12.52	13.11	13.34	13.53	14.13	14.35
PAVIA	Cairoli/Emanuele Filiberto	06.13	06.30	06.49	07.08	07.35	07.56	08.15	08.40	08.58	09.18	09.38	09.56	10.14	10.35	10.56	11.17	11.38	11.57	12.14	12.34	12.54	13.13	13.36	13.55	14.15	14.37
PAVIA	Castello (Musei Civici)	06.15	06.32	06.51	07.10	07.37	07.58	08.17	08.42	09.00	09.20	09.40	09.58	10.16	10.37	10.58	11.19	11.40	11.59	12.16	12.36	12.56	13.15	13.38	13.57	14.17	14.39
PAVIA	Matteotti/Griziotti/Petrarca	06.16	06.33	06.52	07.11	07.38	07.59	08.18	08.43	09.01	09.21	09.41	09.59	10.17	10.38	10.59	11.20	11.41	12.00	12.17	12.37	12.57	13.16	13.39	13.58	14.18	14.40
PAVIA	Matteotti/Dante	06.16	06.33	06.52	07.12	07.39	08.00	08.19	08.44	09.02	09.22	09.42	10.00	10.18	10.39	11.00	11.21	11.42	12.01	12.18	12.38	12.58	13.17	13.40	13.59	14.19	14.41
PAVIA	FS - Della Stazione	06.20	06.37	06.56	07.16	07.43	08.04	08.23	08.49	09.07	09.27	09.47	10.05	10.23	10.44	11.05	11.26	11.47	12.06	12.23	12.43	13.03	13.21	13.44	14.03	14.23	14.45
PAVIA	Filzi/Dante	06.21	06.38	06.57	07.17	07.44	08.05	08.24	08.50	09.08	09.28	09.48	10.06	10.24	10.45	11.06	11.27	11.48	12.07	12.24	12.44	13.04	13.22	13.45	14.04	14.24	14.46
PAVIA	Trieste/Longobardi	06.22	06.39	06.58	07.18	07.45	08.06	08.25	08.51	09.09	09.29	09.49	10.07	10.25	10.46	11.07	11.28	11.49	12.08	12.25	12.45	13.05	13.23	13.46	14.05	14.25	14.47
PAVIA	Golgi (Policlinico S.Matteo)	06.23	06.40	06.59	07.19	07.47	08.08	08.27	08.53	09.11	09.31	09.51	10.09	10.27	10.48	11.09	11.30	11.51	12.10	12.27	12.47	13.07	13.25	13.48	14.07	14.27	14.49
PAVIA	Golgi/Taramelli	06.23	06.40	06.59	07.19	07.47	08.08	08.27	08.53	09.11	09.31	09.51	10.09	10.27	10.48	11.09	11.30	11.51	12.10	12.27	12.47	13.07	13.25	13.48	14.07	14.27	14.49
PAVIA	Taramelli/Forlanini	06.24	06.41	07.00	07.20	07.48	08.09	08.28	08.55	09.13	09.33	09.53	10.11	10.29	10.50	11.11	11.32	11.53	12.12	12.29	12.49	13.08	13.26	13.49	14.08	14.28	14.50
PAVIA	Taramelli/Don. Sangue (AVIS)	06.25	06.42	07.01	07.21	07.49	08.10	08.29	08.55	09.13	09.33	09.53	10.11	10.29	10.50	11.11	11.32	11.53	12.12	12.29	12.49	13.09	13.27	13.50	14.09	14.29	14.51
PAVIA	Ferrata (Tangenziale Ovest)	06.26	06.43	07.02	07.22	07.50	08.11	08.30	08.57	09.15	09.35	09.55	10.13	10.31	10.52	11.13	11.34	11.55	12.14	12.31	12.51	13.10	13.28	13.51	14.10	14.30	14.52
PAVIA	Ferrata (Mondino)		06.43	07.02				08.30													12.51						14.52
PAVIA	Ferrata/Cascinazza		06.43	07.02				08.31													12.52						14.52
PAVIA	Giulotto (Green Campus)		06.45	07.04				08.33													12.54						14.54
PAVIA	Cascinazza (Campus Aquae)		06.46	07.05				08.34													12.55						14.55
PAVIA	Cascinazza/Maugeri	06.27			07.23	07.51	08.12		08.58	09.16	09.36	09.56	10.14	10.32	10.53	11.14	11.35	11.56	12.15	12.32		13.11	13.29	13.52	14.11	14.31	
PAVIA	Maugeri (Ist. Maugeri-Mondino)	06.28	06.47	07.06	07.24	07.52	08.13	08.35	08.59	09.17	09.37	09.57	10.15	10.33	10.54	11.15	11.36	11.57	12.16	12.33	12.56	13.12	13.30	13.53	14.12	14.32	14.56

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CURA C.	Dosso/Della Spiga				06.45	07.11	07.31		08.15			09.16						11.16						13.15			14.15
CURA C.	Prado - Della Paiola/Art.				06.51	07.17	07.37		08.21			09.21						11.21						13.20			14.20
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PAVIA	Pensa/Maciachini	06.03	06.20	06.39	06.56	07.22	07.43	08.01	08.27	08.46	09.06	09.26	09.44	10.02	10.23	10.44	11.05	11.26	11.45	12.02	12.22	12.42	13.02	13.25	13.44	14.04	14.25
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PAVIA	Ceva/Marchesi	06.06	06.23	06.42	06.59	07.25	07.46	08.05	08.30	08.49	09.09	09.29	09.47	10.05	10.26	10.47	11.08	11.29	11.48	12.05	12.25	12.45	13.05	13.28	13.47	14.07	14.28
PAVIA	Treves/Ortaglia Ospedale	06.07	06.24	06.43	07.00	07.26	07.47	08.06	08.31	08.50	09.10	09.30	09.48	10.06	10.27	10.48	11.09	11.30	11.49	12.06	12.26	12.46	13.06	13.29	13.48	14.08	14.29
PAVIA	Treves/Vigentina	06.08	06.25	06.44	07.01	07.27	07.48	08.07	08.32	08.51	09.11	09.31	09.49	10.07	10.28	10.49	11.10	11.31	11.50	12.07	12.27	12.47	13.07	13.30	13.49	14.09	14.30
PAVIA	Vigentina, 17 (Parco)	06.09	06.26	06.45	07.02	07.28	07.49	08.08	08.33	08.52	09.12	09.32	09.50	10.08	10.29	10.50	11.11	11.32	11.51	12.08	12.28	12.48	13.08	13.31	13.50	14.10	14.31
PAVIA	Tasso/Della Torretta	06.10	06.27	06.46	07.04	07.30	07.51	08.10	08.35	08.54	09.14	09.34	09.52	10.10	10.31	10.52	11.13	11.34	11.53	12.10	12.30	12.50	13.09	13.32	13.51	14.11	14.33
PAVIA	Tasso/Bona di Savoia	06.11	06.28	06.47	07.04	07.31	07.52	08.11	08.36	08.54	09.14	09.34	09.52	10.10	10.31	10.52	11.13	11.34	11.53	12.10	12.30	12.50	13.10	13.33	13.52	14.12	14.33
PAVIA	Tasso/Alzaia/Colesino	06.12	06.29	06.48	07.06	07.33	07.54	08.13	08.38	08.56	09.16	09.36	09.54	10.12	10.33	10.54	11.15	11.36	11.55	12.12	12.32	12.52	13.11	13.34	13.53	14.13	14.35
PAVIA	Cairoli/Emanuele Filiberto	06.13	06.30	06.49	07.08	07.35	07.56	08.15	08.40	08.58	09.18	09.38	09.56	10.14	10.35	10.56	11.17	11.38	11.57	12.14	12.34	12.54	13.13	13.36	13.55	14.15	14.37
PAVIA	Castello (Musei Civici)	06.15	06.32	06.51	07.10	07.37	07.58	08.17	08.42	09.00	09.20	09.40	09.58	10.16	10.37	10.58	11.19	11.40	11.59	12.16	12.36	12.56	13.15	13.38	13.57	14.17	14.39
PAVIA	Matteotti/Griziotti/Petrarca	06.16	06.33	06.52	07.11	07.38	07.59	08.18	08.43	09.01	09.21	09.41	09.59	10.17	10.38	10.59	11.20	11.41	12.00	12.17	12.37	12.57	13.16	13.39	13.58	14.18	14.40
PAVIA	Matteotti/Dante	06.16	06.33	06.52	07.12	07.39	08.00	08.19	08.44	09.02	09.22	09.42	10.00	10.18	10.39	11.00	11.21	11.42	12.01	12.18	12.38	12.58	13.17	13.40	13.59	14.19	14.41
PAVIA	FS - Della Stazione	06.20	06.37	06.56	07.16	07.43	08.04	08.23	08.49	09.07	09.27	09.47	10.05	10.23	10.44	11.05	11.26	11.47	12.06	12.23	12.43	13.03	13.21	13.44	14.03	14.23	14.45
PAVIA	Filzi/Dante	06.21	06.38	06.57	07.17	07.44	08.05	08.24	08.50	09.08	09.28	09.48	10.06	10.24	10.45	11.06	11.27	11.48	12.07	12.24	12.44	13.04	13.22	13.45	14.04	14.24	14.46
PAVIA	Trieste/Longobardi	06.22	06.39	06.58	07.18	07.45	08.06	08.25	08.51	09.09	09.29	09.49	10.07	10.25	10.46	11.07	11.28	11.49	12.08	12.25	12.45	13.05	13.23	13.46	14.05	14.25	14.47
PAVIA	Golgi (Policlinico S.Matteo)	06.23	06.40	06.59	07.19	07.47	08.08	08.27	08.53	09.11	09.31	09.51	10.09	10.27	10.48	11.09	11.30	11.51	12.10	12.27	12.47	13.07	13.25	13.48	14.07	14.27	14.49
PAVIA	Golgi/Taramelli	06.23	06.40	06.59	07.19	07.47	08.08	08.27	08.53	09.11	09.31	09.51	10.09	10.27	10.48	11.09	11.30	11.51	12.10	12.27	12.47	13.07	13.25	13.48	14.07	14.27	14.49
PAVIA	Taramelli/Forlanini	06.24	06.41	07.00	07.20	07.48	08.09	08.28	08.55	09.13	09.33	09.53	10.11	10.29	10.50	11.11	11.32	11.53	12.12	12.29	12.49	13.08	13.26	13.49	14.08	14.28	14.50
PAVIA	Taramelli/Don. Sangue (AVIS)	06.25	06.42	07.01	07.21	07.49	08.10	08.29	08.55	09.13	09.33	09.53	10.11	10.29	10.50	11.11	11.32	11.53	12.12	12.29	12.49	13.09	13.27	13.50	14.09	14.29	14.51
PAVIA	Ferrata (Tangenziale Ovest)	06.26	06.43	07.02	07.22	07.50	08.11	08.30	08.57	09.15	09.35	09.55	10.13	10.31	10.52	11.13	11.34	11.55	12.14	12.31	12.51	13.10	13.28	13.51	14.10	14.30	14.52
PAVIA	Ferrata (Mondino)		06.43	07.02				08.30													12.51						14.52
PAVIA	Ferrata/Cascinazza		06.43	07.02				08.31													12.52						14.52
PAVIA	Giulotto (Green Campus)		06.45	07.04				08.33													12.54						14.54
PAVIA	Cascinazza (Campus Aquae)		06.46	07.05				08.34													12.55						14.55
PAVIA	Cascinazza/Maugeri	06.27			07.23	07.51	08.12		08.58	09.16	09.36	09.56	10.14	10.32	10.53	11.14	11.35	11.56	12.15	12.32		13.11	13.29	13.52	14.11	14.31	
PAVIA	Maugeri (Ist. Maugeri-Mondino)	06.28	06.47	07.06	07.24	07.52	08.13	08.35	08.59	09.17	09.37	09.57	10.15	10.33	10.54	11.15	11.36	11.57	12.16	12.33	12.56	13.12	13.30	13.53	14.12	14.32	14.56

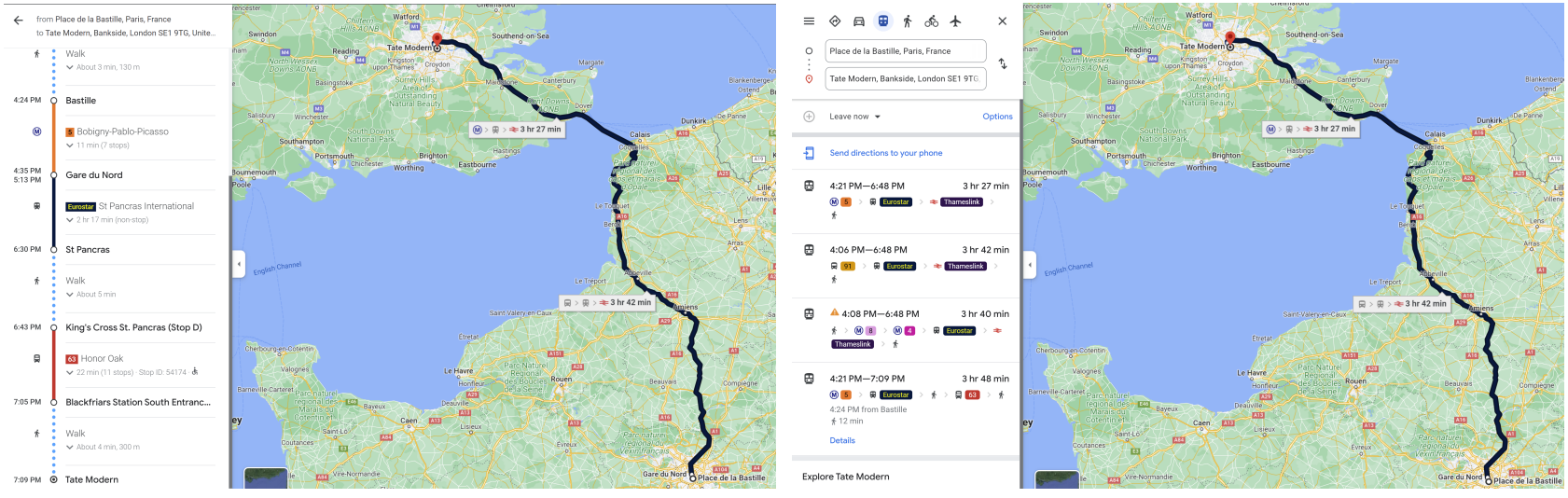
Multimodal schedule-based routing

Definition 2 (Journey)

A journey $J \in \mathcal{J}$ is defined as a sequence of trips and transfers.

Definition 3 (Domination criteria)

$J_1 \preceq J_2$: journey J_1 *dominates* journey J_2, if J_1 is no worse in any criteria (time and/or number of transfer) than journey J_2.



Routing queries

Definition 4 (Earliest Arrival Problem)

Given a source p_s and a target p_t stop, a departure time τ we have to find a journey J that departs from p_s no earlier than τ and arrive in p_t as soon as possible.

Routing queries

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In this project, we focus on:

Definition 7 (Allpairs Earliest Arrival Problem)

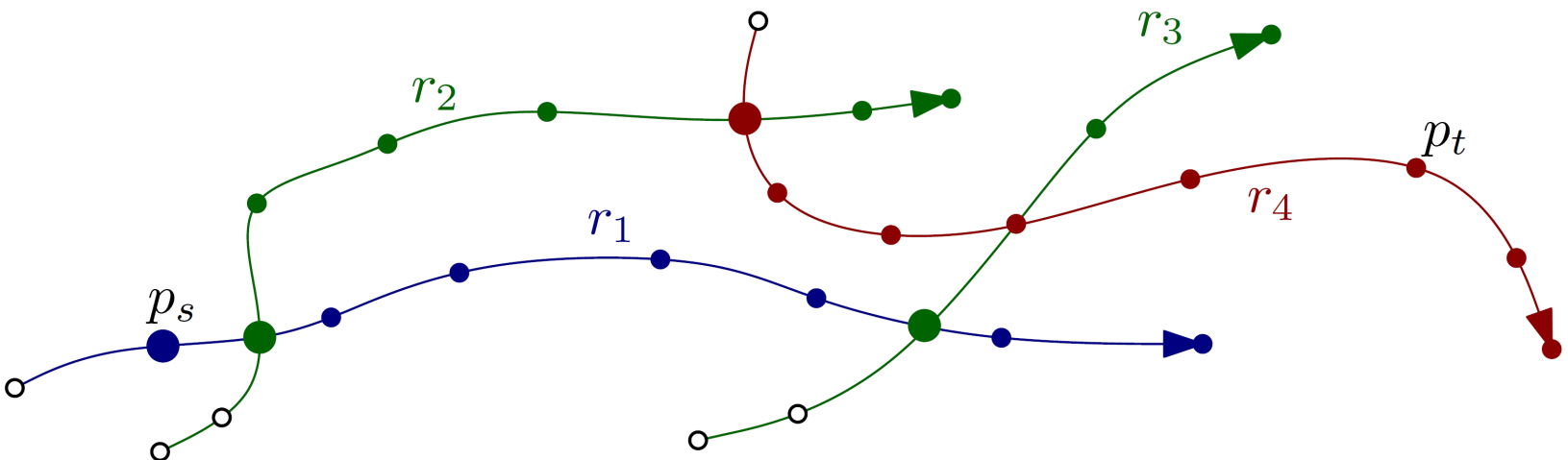
Given a subset of stops $\mathcal{Q} \subseteq \mathcal{S}$ and departure time τ. we have to find for every pair $p_s, p_t \in \mathcal{Q}$ the earliest arrival time from p_s to p_t leaving from p_s no earlier than τ. We want to compute both the arrival time and the whole journey.

State of the art on Multimodal Transit Routing

- Modeling schedule-based networks: [PSWZ08]
- Introduction of RAPTOR [DDP+13, DPW15], which outperformed previous Timed Dijkstra algorithms
- Three criteria routing optimization: [PS22]
- OpenTripPlanner (analytics version v1.5, Java-based)
  `https://www.opentripplanner.org/`
- Online sketch route planning for fare optimization: [CBvdL17, CS19].
  On GitHub, spin-off of OpenTripPlanner:
  `https://github.com/conveyal/r5`

RAPTOR in a nutshell

- The RAPTOR algorithm is designed for one-to-many queries, and it is optimized for one-to-one query.
- The RAPTOR algorithm runs in rounds: At each round k, it finds the earliest arrival time to every stop by taking at most k trips, i.e., $(k-1)$ transfers.
- The RAPTOR algorithm associates with each stop p a multilabel $(\tau_0(p), \tau_1(p), \ldots, \tau_K(p))$ where $\tau_i(p)$ represents the earliest known arrival time at p with up to i trips.
- Example:



Section 4

1 Introduction

2 The JRC case

3 Multimodal routing

4 VelociRAPTOR

5 Ongoing work



VelociRAPTOR

1. We focus on the **All-to-All Earliest Arrival Problem** for all the journeys in the time period `[startTime, endTime]`, with at most `k` transfers.

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5. ONGOING: We are anticipating some post-processing analysis to reduce the output size
6. ANSI C++17 implementation (crucial for managing memory)

Dataset: GTFS for Estonia, Netherlands, Switzerland

		Estonia	Netherlands	Switzerland
Routes	All	2 170	2 391	732 107
	Buses+Metro	2 148	2 236	634 953
	Train	22	145	93 799
Trips	All	30 311	596 011	808 584
	Buses+Metro	29 877	543 792	635 746
	Train	434	29 904	169 483
Stops	All	15 729	45 345	37 183
	Buses+Metro	15 491	43 896	32 080
	Train	238	1 214	6 018
StopsTime	All	695 049	11 285 190	12 315 599
	Buses+Metro	688 501	10 522 046	10 336 282
	Train	6 548	308 447	1 933 291

Data sources

Netherlands: `https://gtfs.ovapi.nl/`

Switzerland: `https://gtfs.geops.ch/`

OR in practice: Aggressive Preprocessing while Parsing

1. Parse routes only of a given set of `vehicleTypes`.
2. Parse trips only of the parsed routes (i.e., filtered by vehicle type) and with service compatibility.
3. Parse stoptime events only for existing trips, and with a filter on the time window of interest: we are not interested in stoptime events earlier than `startTime` and later then `maxTime`.
4. Parse and keep in memory only stops which are used by at least a trip (i.e., appearing in at least a stoptime event).
5. Compose the parsed stoptimes into trips (with more than a single stoptime). Discard the remaining trips.
6. Aggregate nearby stops into a single one, to reduce the number of One-To-All queries.

   VERY IMPORTANT: during the parsing process, we create new internal sequential integer IDs, which are mapped to external IDs to avoid hashtable-based data structures.

Results for Aggressive Parsing

`startTime=7h00` vs `maxTime=startTime + X hours`

	maxTime	Estonia	Netherlands	Switzerland
Routes	24 hours	2 170	2 391	732 107
	3 hours	1 138	2 277	138 131
	2 hours	1 042	2 235	99 158
Trips	24 hours	30 311	596 011	808 584
	3 hours	6 810	115 042	150 110
	2 hours	5 107	79 155	108 267
Stops	24 hours	15 729	45 345	37 183
	3 hours	13 087	43 888	35 039
	2 hours	12 522	43 306	34 435
StopsTime	24 hours	695 049	11 285 190	12 315 599
	3 hours	137 159	1 936 728	2 038 256
	2 hours	96 516	1 250 476	1 389 795

Effect of train stations aggregation (merged train stops within 250 meters):

		Estonia	Netherlands	Switzerland
Stops	Train	238	1 214	6 018
	Merged	118	503	3 161

Parsing and Preprocessing: Runtime in seconds

Parameters: `maxTransfers`=2, `startTime`=7h00, `maxTime`=9.h00

Parsing: runtime in secs to parse the whole GTFS feed

Transfers: runtime in secs to compute all possible transfers between pairs of stops

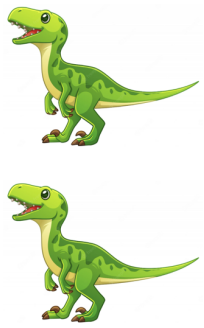
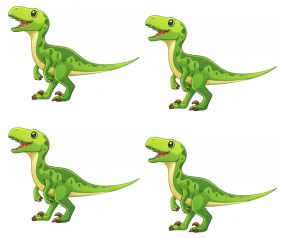
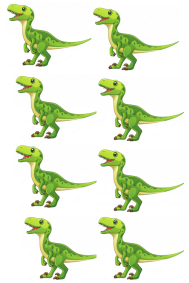
All-to-All (2h): runtime in secs, all-to-all queries with max 2 hours

	Vehicles	Parsing	Transfers	All-to-All (2h)
Estonia	All	0.25	10.18	25.73
	Trains	0.09	0.01	0.04
Netherlands	All	6.29	114.83	210.412
	Trains	1.74	0.19	0.85
Switzerland	All	5.02	84.62	158.032
	Trains	2.28	1.73	8.20

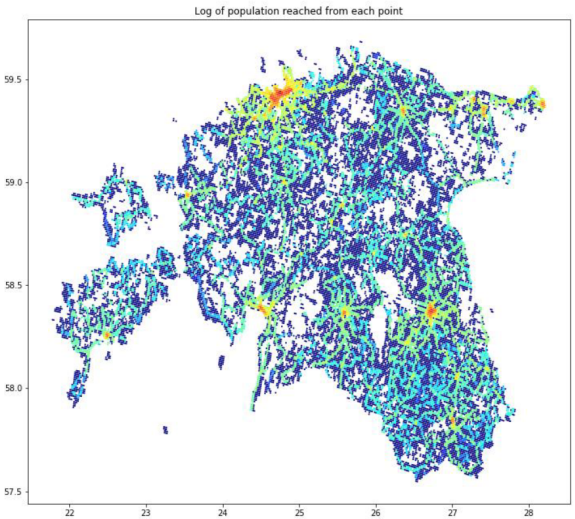
Multithread Performances, VelociRAPTOR v0.5.0

Laptop DELL XPS 13, i7 11th gen 2.8GHz, 32 GB RAM. Windows 10, compiler MS-VS2019, standard optimization flags. ANSI C++17 using std::thread.

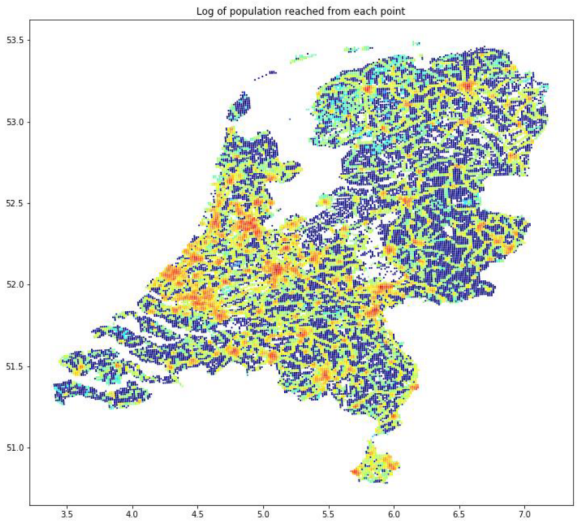
		Parsing	Transfers	all-to-all (5h)	Journeys
Estonia	1 threads	0.10	8.1	157.8	30 482 773
	2 threads			105.3	
	4 threads			55.0	
	8 threads			37.2	
Netherlands	1 threads	2.33	108.2	1797.4	311 951 661 812
	2 threads			1159.8	
	4 threads			684.0	
	8 threads			546.8	
Switzerland	1 threads	2.5	73.5	1789.9	159 246 667
	2 threads			569.0	
	4 threads			446.5	
	8 threads			421.3	

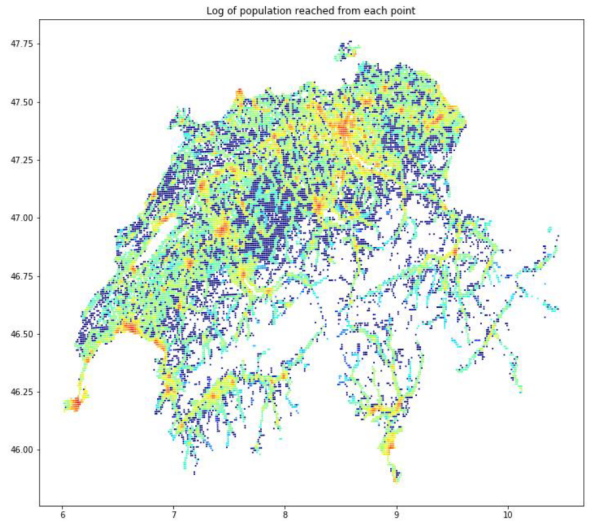
Back to policy makers: Accessibility Maps



EE



NL



CH

Max_time = 2h, max walking distance between stations = 1km, max transfers = 2, all means of transport

Disclaimer: these are not official EU results, but rather a test of what the algorithm can do

Section 5

1 Introduction

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Future Works

- Further scale to larger input size. Target: the Germany GTFS
- Integration with OSM for walk and bike paths for transfers
- Improving the performance for One-to-All queries by exploiting OR techniques with better upper bounding strategies
- Improving the performance for the sequence of One-to-All queries (re-use partial information from queries along the same route)
- Anticipating accessibility analysis into VelociRAPTOR



QUESTIONS?


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Evidence-based transit and land use sketch planning using interactive accessibility methods on combined schedule and headway-based networks.
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