From moving vehicles to moving people: mobility as a service

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Outline

Future of transportation systems

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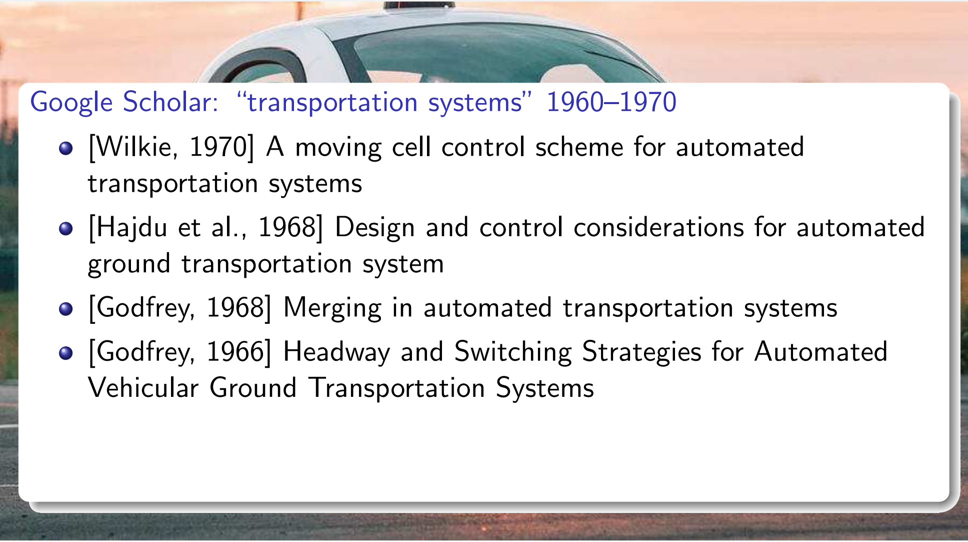
Google Scholar: "transportation systems" 1960–1970

- [Wilkie, 1970] A moving cell control scheme for automated transportation systems

Future of transportation systems



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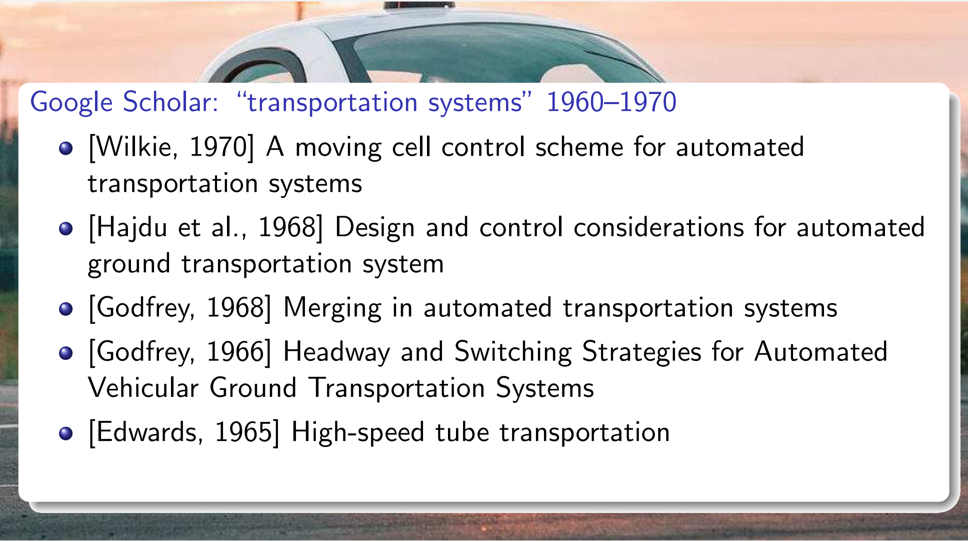

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What has changed?

What has changed?

Technology

What has changed?

Behavior

Outline

Mobility as a service

Mobility as a service

[Hietanen, 2014]

A mobility distribution model that deliver users' transport needs through a single interface of a service provider.

Core characteristics [Jittrapirom et al., 2017]

Integration of transport modes

- Multi-modal
- Encourage public transportation
- Beyond the city boundaries: flights, ferries, etc.

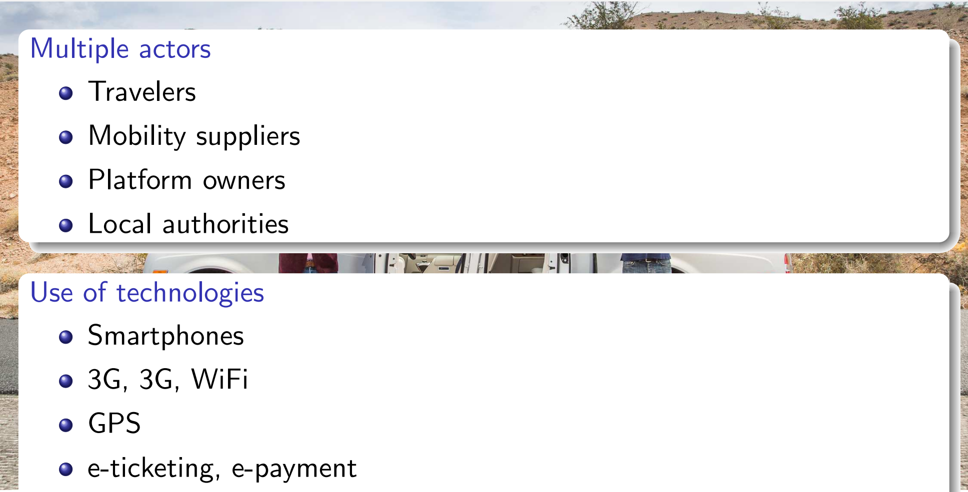
Tariff options

- Mobility package
- Pay as you go

One platform

- Digital platform
- All services available: planning, booking, tickets, payment, real-time information

Core characteristics [Jittrapirom et al., 2017]



Multiple actors

- Travelers
- Mobility suppliers
- Platform owners
- Local authorities

Use of technologies

- Smartphones
- 3G, 3G, WiFi
- GPS
- e-ticketing, e-payment
- IoT
- Data management

Core characteristics [Jittrapirom et al., 2017]

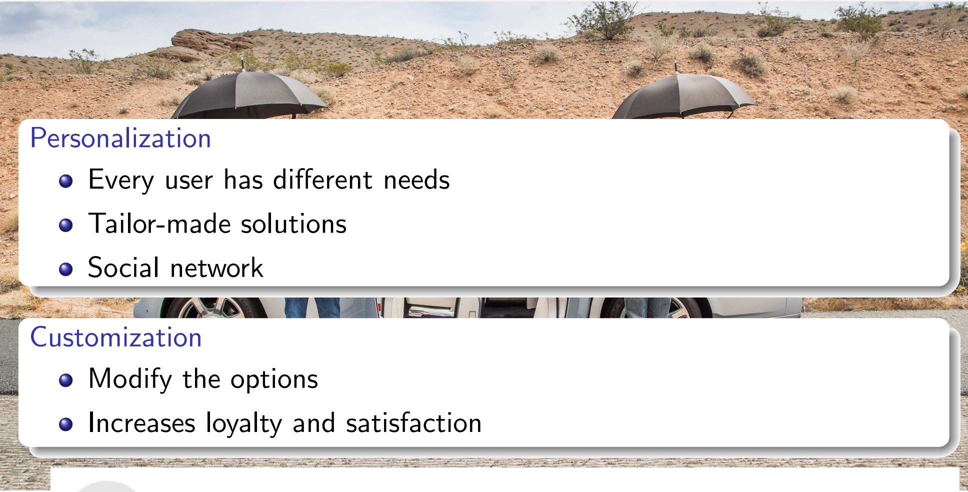
Demand orientation

- User-centric paradigm
- Best from customer's perspective
- Demand responsive

Registration requirement

- Individual or household
- Necessary for payment
- Service personalization

Core characteristics [Jittrapirom et al., 2017]



Personalization

- Every user has different needs
- Tailor-made solutions
- Social network

Customization

- Modify the options
- Increases loyalty and satisfaction

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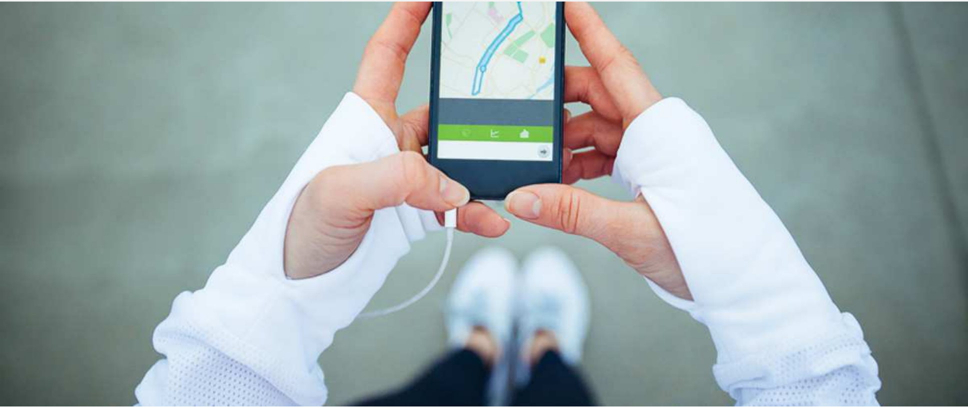
Mobility as a service

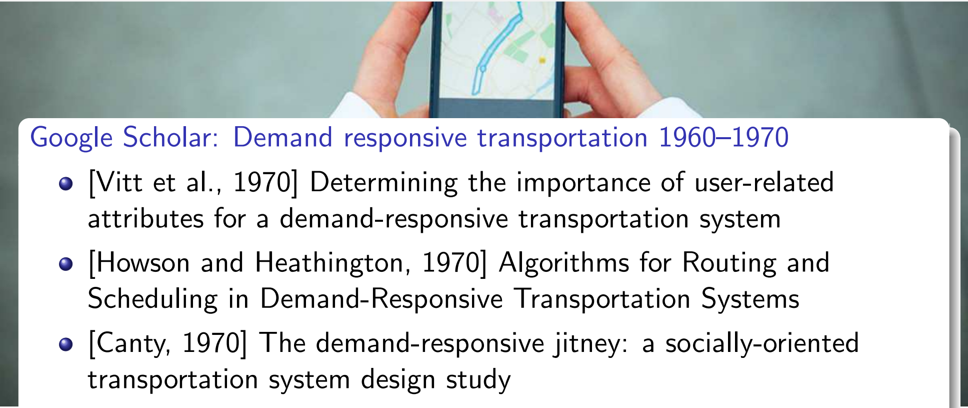
Key challenges [Jittrapirom et al., 2017]

- Demand-side modeling
- Supply-side modeling
- Governance and business model to match supply and demand

Demand responsive transportation systems



Demand responsive transportation systems



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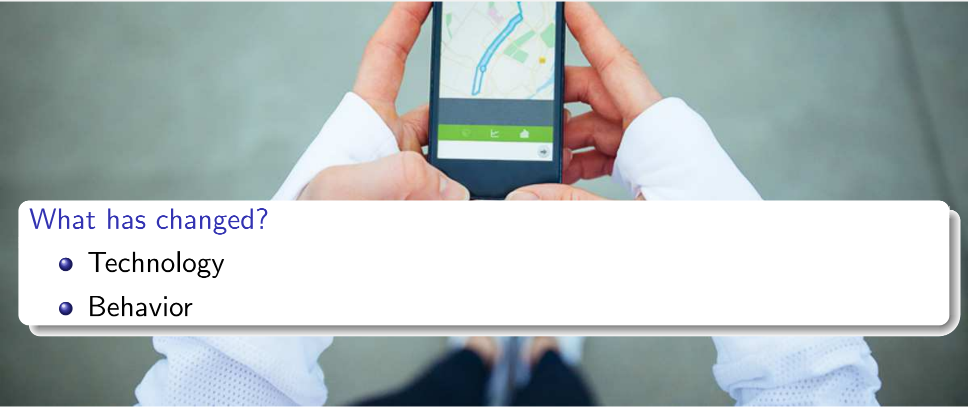
Demand responsive transportation systems



What has changed?

- Technology
- Behavior

Outline

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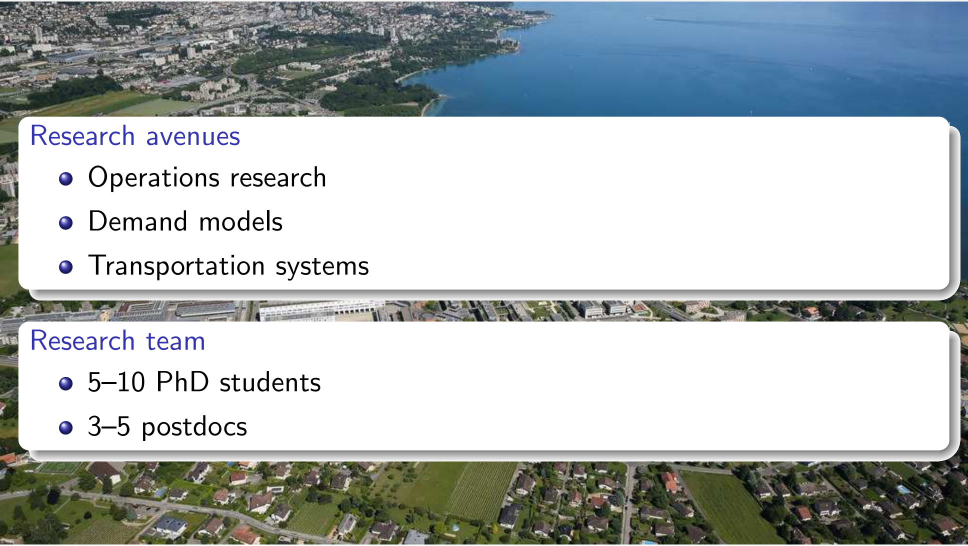


Research avenues

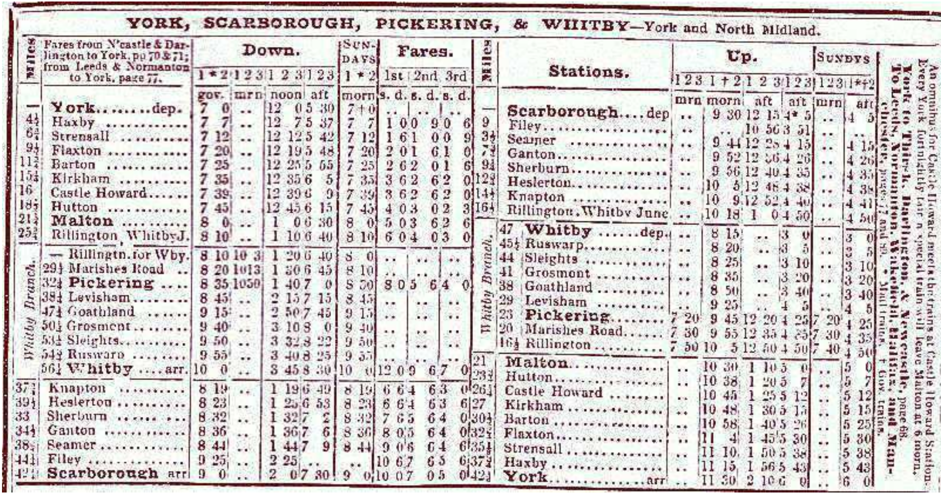
- Operations research
- Demand models
- Transportation systems

Research team

- 5–10 PhD students
- 3–5 postdocs

Outline

Timetables Source: Bradshaw's Guide



YORK, SCARBOROUGH, PICKERING, & WHITBY—York and North Midland.

Fares from N'castle & Darlington to York, pp 70 & 71; from Leeds & Normanton to York, page 77.

Miles	Stations	Down 1*2 gov.	Down 1 2 3 mrn	Down 1 2 3 noon	Down 1 2 3 aft	Sundays 1*2 morn	Fares 1st s. d.	Fares 2nd s. d.	Fares 3rd s. d.
—	York......dep.	7 0	..	12 0	5 30	7†0	..	..	..
4¼	Haxby	7 7	..	12 7	5 37	7 7	1 0	0 9	0 6
6¾	Strensall	7 12	..	12 12	5 42	7 12	1 6	1 0	0 9
9¼	Flaxton	7 20	..	12 19	5 48	7 20	2 0	1 6	1 0
11¾	Barton	7 25	..	12 25	5 55	7 25	2 6	2 0	1 6
15¼	Kirkham	7 35	..	12 35	6 5	7 35	3 6	2 6	2 0
16	Castle Howard	7 39	..	12 39	6 9	7 39	3 6	2 6	2 0
18½	Hutton	7 45	..	12 45	6 15	7 45	4 0	3 0	2 3
21¼	**Malton**	8 0	..	1 0	6 30	8 0	5 0	3 6	2 6
25¾	Rillington, Whitby J.	8 10	..	1 10	6 40	8 10	6 0	4 0	3 0
Whitby Branch. —	Rillingtn. for Wby.	8 10	10 3	1 20	6 40	8 0	..	..	..
29¼	Marishes Road	8 20	1013	1 30	6 45	8 10	..	..	..
32¼	**Pickering**	8 35	1050	1 40	7 0	8 30	8 0	5 6	4 0
38¼	Levisham	8 45	..	2 15	7 15	8 45	..	..	..
47¼	Goathland	9 15	..	2 50	7 45	9 15	..	..	..
50¼	Grosmont	9 40	..	3 10	8 0	9 40	..	..	..
53¼	Sleights	9 50	..	3 32	8 22	9 50	..	..	..
54¾	Ruswarp	9 55	..	3 40	8 25	9 55	..	..	..
56¼	**Whitby** ....arr.	10 0	..	3 45	8 30	10 0	12 0	9 6	7 0
37¾	Knapton	8 19	..	1 19	6 49	8 19	6 6	4 6	3 0
39½	Heslerton	8 23	..	1 25	6 53	8 23	6 6	4 6	3 6
33	Sherburn	8 32	..	1 32	7 2	8 32	7 6	5 6	4 0
34½	Ganton	8 36	..	1 36	7 6	8 36	8 0	5 6	4 0
38½	Seamer	8 44	..	1 44	7 9	8 44	9 0	6 6	4 6
44¼	Filey	9 25	..	2 25	..	..	10 6	7 6	5 6
42¾	**Scarborough** arr	9 0	..	2 0	7 30	9 0	10 0	7 0	5 0

Miles	Stations	Up 1 2 3 mrn	Up 1 † 2 morn	Up 1 2 3 aft	Up 1 2 3 aft	Sundays 1 2 3 mrn	Sundays 1*†2 aft
—	**Scarborough**....dep	..	9 30	12 15	4* 5	..	4 5
9	Filey	..	..	10 56	3 51	..	..
3½	Seamer	..	9 44	12 25	4 15	..	4 15
7¾	Ganton	..	9 52	12 36	4 26	..	4 26
9¼	Sherburn	..	9 56	12 40	4 35	..	4 35
12¾	Heslerton	..	10 5	12 48	4 38	..	4 38
14¼	Knapton	..	10 9	12 52	4 40	..	4 41
16¼	Rillington, Whitby Junc	..	10 18	1 0	4 50	..	4 50
Whitby Branch. 47	**Whitby** ......dep.	..	8 15	..	3 0	..	3 0
45½	Ruswarp	..	8 20	..	3 5	..	3 5
44	Sleights	..	8 25	..	3 10	..	3 10
41	Grosmont	..	8 35	..	3 20	..	3 20
38	Goathland	..	8 50	..	3 40	..	3 40
29	Levisham	..	9 25	..	4 5	..	4 5
23	**Pickering**	7 20	9 45	12 20	4 25	7 20	4 25
20	Marishes Road	7 30	9 55	12 35	4 35	7 30	4 35
16½	Rillington	7 50	10 5	12 50	4 50	7 40	4 50
21	**Malton**	..	10 30	1 10	5 0	..	5 0
23¾	Hutton	..	10 38	1 20	5 7	..	5 7
26¼	Castle Howard	..	10 45	1 25	5 12	..	5 12
27	Kirkham	..	10 48	1 30	5 15	..	5 15
30½	Barton	..	10 58	1 40	5 26	..	5 25
32¾	Flaxton	..	11 4	1 45	5 30	..	5 30
35¼	Strensall	..	11 10	1 50	5 38	..	5 38
37¾	Haxby	..	11 15	1 56	5 43	..	5 43
42¼	**York**.........arr	..	11 30	2 10	6 0	..	6 0

York to Thirsk, Darlington, & Newcastle, page 68. To Leeds, Normanton, Wakefield, Halifax, and Manchester, pages 77 and 80. * Mail trains. † Gov. trains.

An omnibus for Castle Howard meets the trains at Castle Howard Station. Every York fortnightly fair a special train will leave Malton at 6 morn.

Timetables

Definition

Set of arrival and departure times of each train at each of its stopping stations.

Input

- Train lines
- Stopping patterns
- Train frequency

Timetables

Cyclic timetables

- Difference between the departure times of two consecutive trains is constant.
- Typically, cycle is 30 or 60 minutes.

Non-cyclic timetables

- No constraint on departure times
- Just buffer time for safety and robustness

Cyclic timetables

Advantages [Graffagnino, 2014]

- attractiveness for the passengers
- gain of efficiency for the overall system
- difficulty to manage a non-cyclic tailor made timetable

Issues

- Costs
- Empty trains

Non-cyclic timetables

Advantages

- Flexibility
- Possibility to adjust to the demand

Issues

- Difficult to implement in practice
- Rolling stocks and crew management more complicated
- Lack of robustness

Hybrid Cyclicity [Robenek et al., 2017]

Motivation

- Combine the advantages of both types
- Passenger-centric design

Definitions

- θ shifted cyclic timetable
- ξ partially cyclic timetable
- Hybrid cyclic timetable

Hybrid Cyclicity [Robenek et al., 2017]

θ shifted cyclic timetable

- Inspired by [Caimi et al., 2011]
- Allow small deviations from strict cyclicity
- If t is the cyclic departure time, values within $[t-\theta, t+\theta]$ are allowed
- $\theta \leq c/2$
- $\theta = c/2$: non-cyclic, $\theta = 0$: cyclic

Hybrid Cyclicity [Robenek et al., 2017]

ξ partially cyclic timetable

- A proportion (ξ%) of trains on a given line can be non-cyclic.
- Decisions to make: what trains are cyclic and what are not?
- Let η be the number of trains on the most used line (say, 16).
- If $\xi = 50\%$, we impose cyclicity on $\eta\xi = 8$ trains per line.
- $\xi = 0$: non-cyclic, $\xi = 100$: cyclic.

Hybrid cyclic timetable

Motivation

Parametric relaxations (θ and ξ) generate complicated timetables, similar to the non-cyclic ones.

Principle

- Schedules non-cyclic trains only in the cycles were there is already a cyclic train being scheduled.
- Same level of service as a cyclic timetable.
- With more flexibility.

Passenger satisfaction

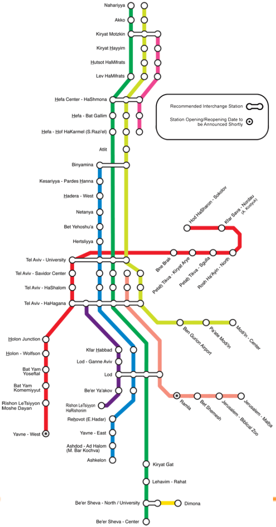
Generalized travel time

- in-vehicle-time
- waiting time at transfers (2.5 min. [Wardman, 2004])
- number of transfers (10.0 min. [de Keizer et al., 2012])
- schedule passenger delay: early arrival (0.5 min. [Small, 1982])
- schedule passenger delay: late arrival (1.0 min. [Small, 1982])

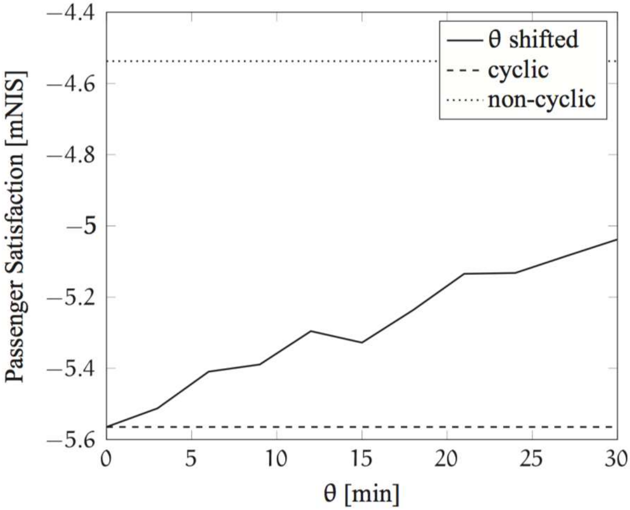
Generalized cost

Use the value of time to transfer travel time into cost.

Case study: Israeli railways



θ-hybrid [Robenek et al., 2017]



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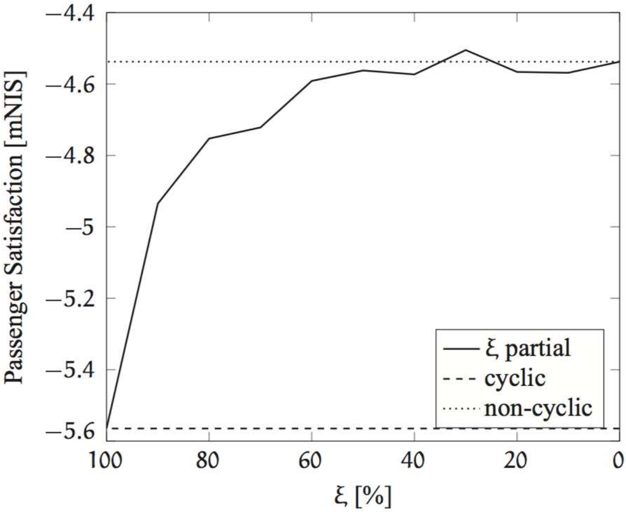
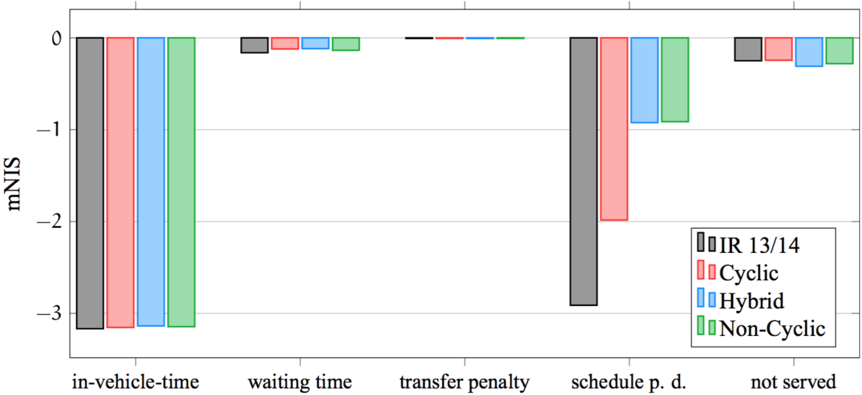


Passenger satisfaction [Robenek et al., 2017]



Beyond timetabling

[Robenek et al., 2018]

Integrate:

- Timetabling
- Demand forecasting
- Pricing

Methodology

Integrate discrete choice models into optimization

Outline

Example: the taxi driver

Context

- A taxi driver has two categories of regular customers:
  - students (2/3 of his clients)
  - business (1/3 of his clients)
- Uber has started to operate in the city.
- How to re-design his prices to optimize his revenues?

Demand model

Discrete choice model

- Two alternatives: the taxi ($i = 1$) and Uber ($i = 2$)
- Two types of customers: students ($n = s$) and business ($n = b$)

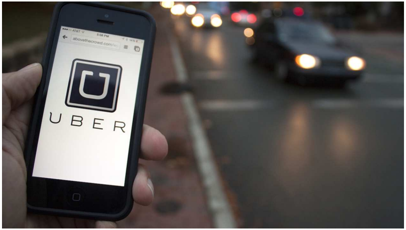
Utility functions

$$
\begin{aligned}
U_{1s} &= -0.3p_1 && +0 \\
U_{2s} &= -0.3p_2 && +3 \\
U_{1b} &= -0.05p_1 && +1 \\
U_{2b} &= -0.05p_2 && +0
\end{aligned}
$$

Logit

$$P_n(i|\mathcal{C}_n) = \frac{e^{V_{in}}}{\sum_{j \in \mathcal{C}_n} e^{V_{jn}}}$$

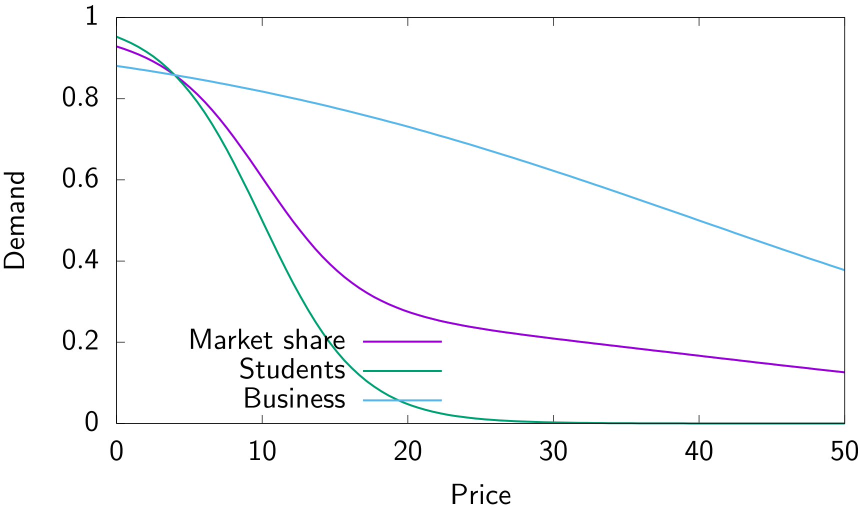
Optimization problem



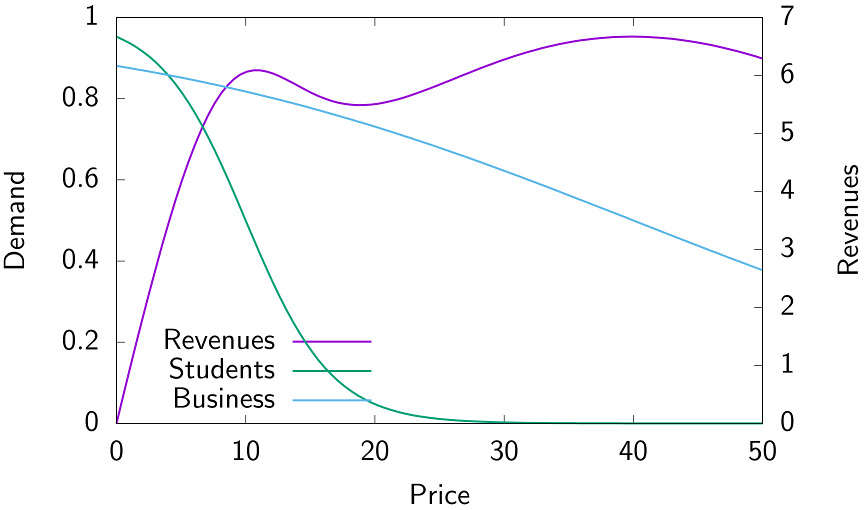
Price: 20 €

Price: ???

Demand


1
0.8
0.6
0.4
0.2
0
Demand
Market share
Students
Business
0
10
20
30
40
50
Price

Demand and revenues



Optimization

Difficult problem

- Non linear
- Non convex/concave
- Multiple local optima

Idea: [Pacheco et al., 2017]

Transform the choice model into a MILP formulation

The main idea

Linearization

- Hopeless to linearize the logit formula (we tried...)
- Anyway, we want to go beyond logit.

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First principles

Each customer solves an optimization problem

The main idea

Linearization

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- Anyway, we want to go beyond logit.

First principles

Each customer solves an optimization problem

Solution

Use the utility and not the probability

A linear formulation

Utility function

$$U_{in} = V_{in} + \varepsilon_{in} = \sum_k \beta_k x_{ink} + f(z_{in}) + \varepsilon_{in}.$$

Simulation

- Assume a distribution for ε_{in}
- E.g. logit: i.i.d. extreme value
- Draw R realizations ξ_{inr}, $r = 1, \ldots, R$
- The choice problem becomes deterministic

Scenarios

Draws

- Draw R realizations ξ_{inr}, $r = 1, \ldots, R$
- We obtain R scenarios

$$U_{inr} = \sum_k \beta_k x_{ink} + f(z_{in}) + \xi_{inr}.$$

- For each scenario r, we can identify the largest utility.
- It corresponds to the chosen alternative.

Current results

Good news

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- It works!
- For any type of choice model
- We tried it on a mixture of logit model from the literature

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- Large scale problem: many draws, many individuals
- Only small instances can be solved with standard software
- We are working on dedicated algorithms (decomposition methods)

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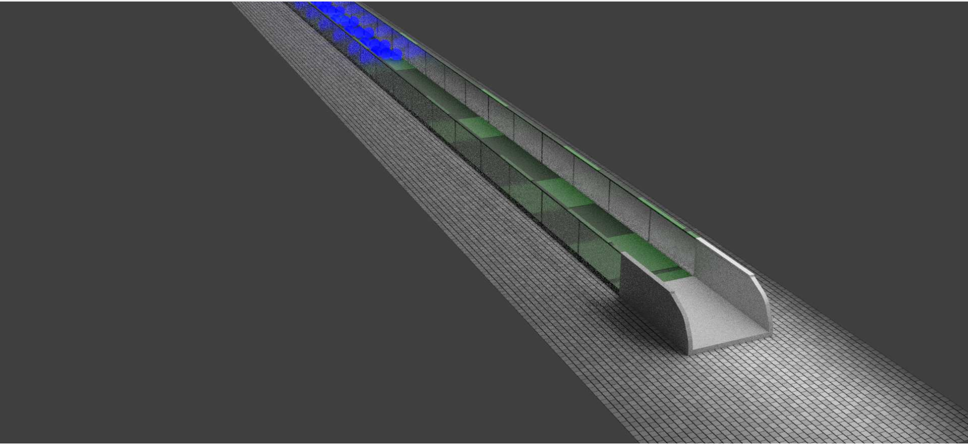
Extensions

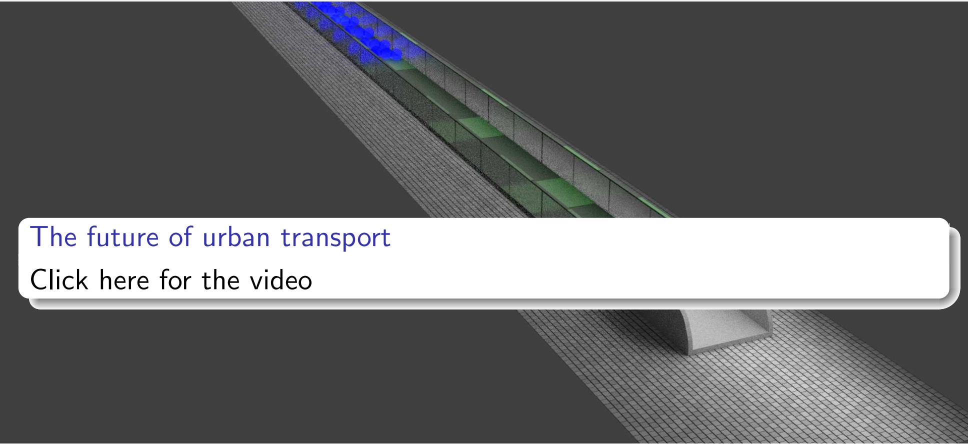
- Behavioral game theory
- Revenue management

Outline

Accelerated Moving Walkways



Accelerated Moving Walkways



The future of urban transport

Click here for the video

Outline

Conclusion

Mobility as a service

- Modern concept
- Integrated system
- Relies on recent technologies
- Demand driven

Research challenges

- Technology
- Behavior

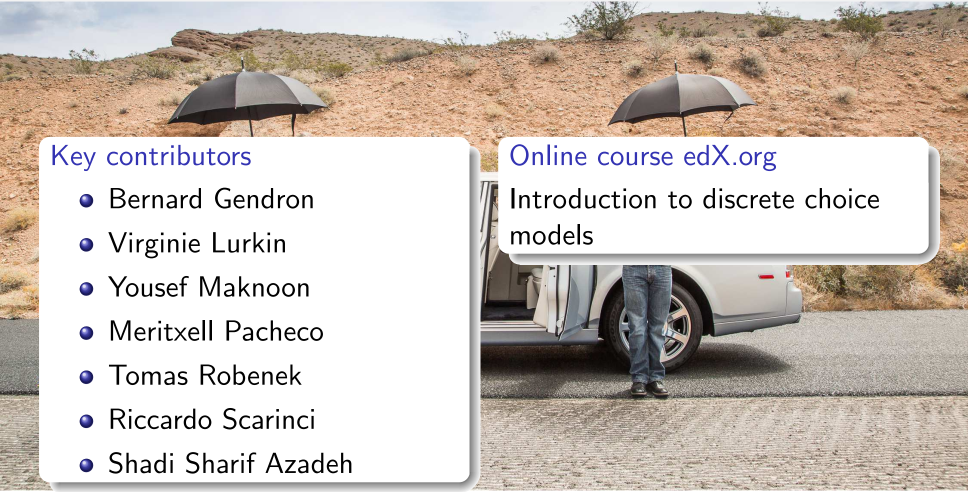
Dank u wel!

Dank u wel!

Key contributors

- Bernard Gendron
- Virginie Lurkin
- Yousef Maknoon
- Meritxell Pacheco
- Tomas Robenek
- Riccardo Scarinci
- Shadi Sharif Azadeh

Dank u wel!



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Online course edX.org

Introduction to discrete choice models

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