From moving vehicles to moving people: mobility as a service

Michel Bierlaire

Transport and Mobility Laboratory
School of Architecture, Civil and Environmental Engineering
Ecole Polytechnique Fédérale de Lausanne

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Outline

1 Back to the future

2 Mobility as a service

3 Transport and Mobility Laboratory @ EPFL

4 Timetables

5 Choice models and optimization

6 Accelerating moving walkways

7 Conclusion
Future of transportation systems
Future of transportation systems


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


- [Wilkie, 1970] A moving cell control scheme for automated transportation systems
- [Hajdu et al., 1968] Design and control considerations for automated ground transportation system
Future of transportation systems


- [Wilkie, 1970] A moving cell control scheme for automated transportation systems
- [Hajdu et al., 1968] Design and control considerations for automated ground transportation system
- [Edwards, 1965] High-speed tube transportation
Future of transportation systems


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- [Hajdu et al., 1968] Design and control considerations for automated ground transportation system
- [Edwards, 1965] High-speed tube transportation
What has changed?
What has changed?

Technology
What has changed?

Behavior
Mobility as a service

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Mobility as a service
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
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

Google Scholar: Demand responsive transportation 1960–1970

- [Vitt et al., 1970] Determining the importance of user-related attributes for a demand-responsive transportation system
- [Howson and Heathington, 1970] Algorithms for Routing and Scheduling in Demand-Responsive Transportation Systems
- [Canty, 1970] The demand-responsive jitney: a socially-oriented transportation system design study
- [Hall, 1970] Results of a personalized transit study
Demand responsive transportation systems

What has changed?
- Technology
- Behavior
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Research avenues

- Operations research
- Demand models
- Transportation systems

Research team

- 5–10 PhD students
- 3–5 postdocs
### Timetables

Source: Bradshaw’s Guide

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<td>York</td>
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**Notes:**
- Timetables from York to Whitby, including stops at Haxby, Knpton, Castle Howard, Kirkham, Barton, and Flaxton.
- Fares from York to Whitby vary depending on distance.
- Special timetables for Sundays and Mondays.

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**Source:** Bradshaw’s Guide
Timetables

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

Input
- Train lines
- Stopping patterns
- Train frequency
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

- $\theta$ shifted cyclic timetable
- $\xi$ partially cyclic timetable
- Hybrid cyclic timetable
Hybrid Cyclicity [Robenek et al., 2017]

$\theta$ 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]

$\xi$ partially cyclic timetable

- A proportion ($\xi\%$) of trains on a given line can be non-cyclic.
- Decisions to make: what trains are cyclic and what are not?
- Let $\eta$ 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 ($\theta$ and $\xi$) 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
$\theta$-hybrid [Robenek et al., 2017]
ξ-hybrid [Robenek et al., 2017]
Passenger satisfaction [Robenek et al., 2017]
Beyond timetabling

[Intobenek et al., 2018]

Integrate:
- Timetabling
- Demand forecasting
- Pricing

Methodology

Integrate discrete choice models into optimization
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

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

Logit

$$
P_n(i|C_n) = \frac{e^{V_{in}}}{\sum_{j \in C_n} e^{V_{jn}}}
$$
Optimization problem

Price: 20 €

Price: ???
Demand

The graph shows the demand for different market segments (Students, Business, and Market share) as a function of price. The demand decreases as the price increases, indicating a typical demand curve. The market share segment shows the highest initial demand, followed by students and then business, although all segments decrease significantly with increasing price.
Demand and revenues

![Graph showing demand and revenues as functions of price for different categories: Students, Business, and Revenues. The graph indicates a decrease in demand and an increase in revenues as the price increases.]
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.
The main idea

Linearization

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First principles

Each customer solves an optimization problem
The main idea

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- Hopeless to linearize the logit formula (we tried...)
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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 \( \varepsilon_{in} \)
- E.g. logit: i.i.d. extreme value
- Draw \( R \) realizations \( \xi_{inr} \), \( r = 1, \ldots, R \)
- The choice problem becomes deterministic
Scenarios

Draws

- Draw $R$ realizations $\xi_{inr}, r = 1, \ldots, R$
- 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
Current results

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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
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Accelerated Moving Walkways
Accelerated Moving Walkways

The future of urban transport
Click here for the video
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
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Online course edX.org
Introduction to discrete choice models
Bibliography I


Bibliography III

*Merging in automated transportation systems.*
PhD thesis, Massachusetts Institute of Technology.

Cyclic timetable improvement with train traffic data analysis.  

Design and control considerations for automated ground transportation systems.  

Results of a personalized transit study.  
In *Arizona Conf Roads & Streets Proc.*
Bibliography IV


Bibliography VI

Train timetable design under elastic passenger demand.
*Transportation Research Part B: Methodological.*
Accepted for publication.

The scheduling of consumer activities: work trips.

Determining the importance of user-related attributes for a demand-responsive transportation system.