Determining the Optimal Allocation of Automated Buses

A Study for Kista, Stockholm
Jonas Hatzenbühler, Erik Jenelius, KTH Urban Mobility Group
Research Question
Vehicle Allocation
Improvement through Autonomous Buses

Public Transport System + Autonomous Vehicles

Tradeoff between investment costs and service provided

1st Step: Vehicle Allocation on existing bus lines!
Research Question

Transition Phase

Question

Where should AB systems be deployed based on route network, bus capacity, bus frequency, operator demand and passenger demand?

Assumptions

- All vehicles have the same speed
- All vehicles can operate on the entire network
- People perceive all vehicles the same

Method: Selective Mesoscopic Multi Agent Simulation - BusMezzo

Simulation

- Performance Data
- Existing Database of Stockholm

BusMezzo
Framework
Overview

Strategy Decision

Decision Variables:
- Vehicle Type
- Capacity
- Frequency

Simulation
- Performance Data
- Existing Database of Stockholm

BusMezzo

Evaluation

User Cost ($C_{\text{user}}$)
- Vehicle Crowding
- Waiting Time
- Transfers
- Travel Time
- Denied Boarding

Operator Cost ($C_{\text{operator}}$)
1. Capital Cost
2. Operating Cost

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Model Specification
Operator Cost - Overview

Why?
What?
How?
Results
Learning & Outcomes
Case Study “Kista Area”

Representation

"Extended" Kista Area

- New AB lines
  - 4 Bus stops

- "Representative Lines"
  - Replacement of red lines (Sollentuna <-> Helenelund <-> Kista <-> Husby)
  - Approximation of Passenger Flow based on Demand Data available on other Stops (Interpolation)
  - OD Models of Sollentuna, Helenelund, Kista, Husby

- Simulation
  - entire Stockholm Network
  - Optimization focused on the Kista area
  - Include spillover and network effects in the analysis
Experiment Design
Simplified Strategy Discussion

1. Determining Frequency and Capacity
   - Effect of Frequency and Capacity

![Graph showing total cost vs strategy]

2. Baseline Strategy
   - All buses are conventional
   - Best frequency and capacity

"Autopiloten Strategy"

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Line</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strategy 1</td>
<td>Line 1</td>
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<tr>
<td>Strategy 2</td>
<td>Line 2</td>
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<tr>
<td>Strategy 3</td>
<td>Line 3</td>
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<tr>
<td>Strategy 4</td>
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</tbody>
</table>
Results Case Study
Allocation of Vehicles

Vehicle Type

"Autopiloten Strategy"

High Passenger Load favors deployment of AB Systems

Bad Service by Design

All Autonomous
Autonomous on Line 1 & Line 2

How? What? Why?

5 Learning & Outcomes
4 Results
3 How?
2 What?
1 Why?
Learnings & Consequences

What can we learn for the future of deploying Autonomous Buses?

1. High passenger load is a good indicator for potential autonomous bus lines.

2. No Compensation of poor service by design.

Urban traffic evolution in 24 hours.
Current Work: Simulation-Optimization Framework

Detailed

Input
- a) OD Matrix
- b) Service Network
- c) Cost Parameters

Constraint
- a) Clock Frequency
- b) Capacity Limits
- c) Integer Values

Optimization
- Decision Variables
  - a) Vehicle Capacity per Route
  - b) Frequency per Route
  - c) AB or Conventional

Objective Function
- \( \min (OC + UC) \)
  - OC: Operator Cost
  - UC: User Cost

Multi-Agent Simulation
- Traffic Simulation
- Transit Operations and Control
- Dynamic Path Choice Model
- Real-Time Information Generator

User and Operator costs
- a) Total Travel Time
- b) Passenger Waiting Time
- c) Passenger Onboard Time
- d) Modal Split

Analyze KPI
- a) Waiting Times
- b) Travel Time
- c) Personnel Costs
- d) Maintenance Costs
- e) Operation Costs

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Applications:
- handling of peak hour demand through compensating autonomous buses
  - In off peak hours these buses would drive autonomously on their “original” dedicated route
- Connection of flexible On Demand Service (AV) with scheduled Public Transport (bus, metro, trains)
- Study the effect of smaller vehicles on Transport System
- Dynamic linking of bus routes with parking, charging constraints

Where is the deployment of AB networks most profitable?
Thank you for your attention!

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KTH Stockholm

More Information:
https://www.byv.kth.se/en/avd/tet
https://www.itrl.kth.se/research/projects/sara1
Backup: New Agenda
Results

How to read the graphs?

One Scenario

Color = Objective Value

Decision Variables for this Scenario

One Vehicle Configuration

Different Capacities per Line

Different Frequencies per Line

Vehicle Types

Entire Solution Space

Different Vehicle Configurations

\[ 3^4 = 81 \]

\[ 2^4 = 16 \]
User Cost
Vehicle Configuration 2,2,2,1

1. \( f_1 = 2 \frac{\text{Veh}}{h} \) & \( c_1 = 60 \text{Pas} \)
   \( f_4 = 30 \frac{\text{Veh}}{h} \) & \( c_4 = 10 \text{Pas} \)
   \( \rightarrow \) Bad Network Design

2. High frequency and high capacity generally better for user cost

Mainly due to denied boarding and crowding in the buses
Total Cost
Vehicle Configuration 2,2,2,1

Analysis

1. Sweet Spots for operating
   \[ f_1 = f_4 = 30 \frac{Veh}{h} \]
   &
   \[ c_2 > c_3 = c_4 = P_{max} \]

   \[ f_1 = 2 \frac{Veh}{h} \]
   \[ f_2 = 10 \frac{Veh}{h} \]
   \[ f_4 = 30 \frac{Veh}{h} \]

   &
   \[ c_2 = 120 \text{Pas} \]
   \[ c_1 = 10 \text{Pas} \]

increase in Capacity
increase in Frequency
Bad
Good
1. Introduction of autonomous buses reduces the total cost but does not remove bad network design.

2. Areas which were not operable with conventional buses are operable with autonomous vehicles.