ADAPT-IT

Analysis and **D**evelopment of **A**ttractive **P**ublic **T**ransport through **I**nformation **T**echnology

Real-time Holding Control Strategies for Single and Multiple Public Transport Lines

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Real Time Control of Public Transport Systems

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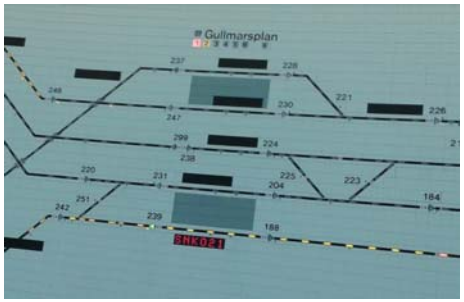
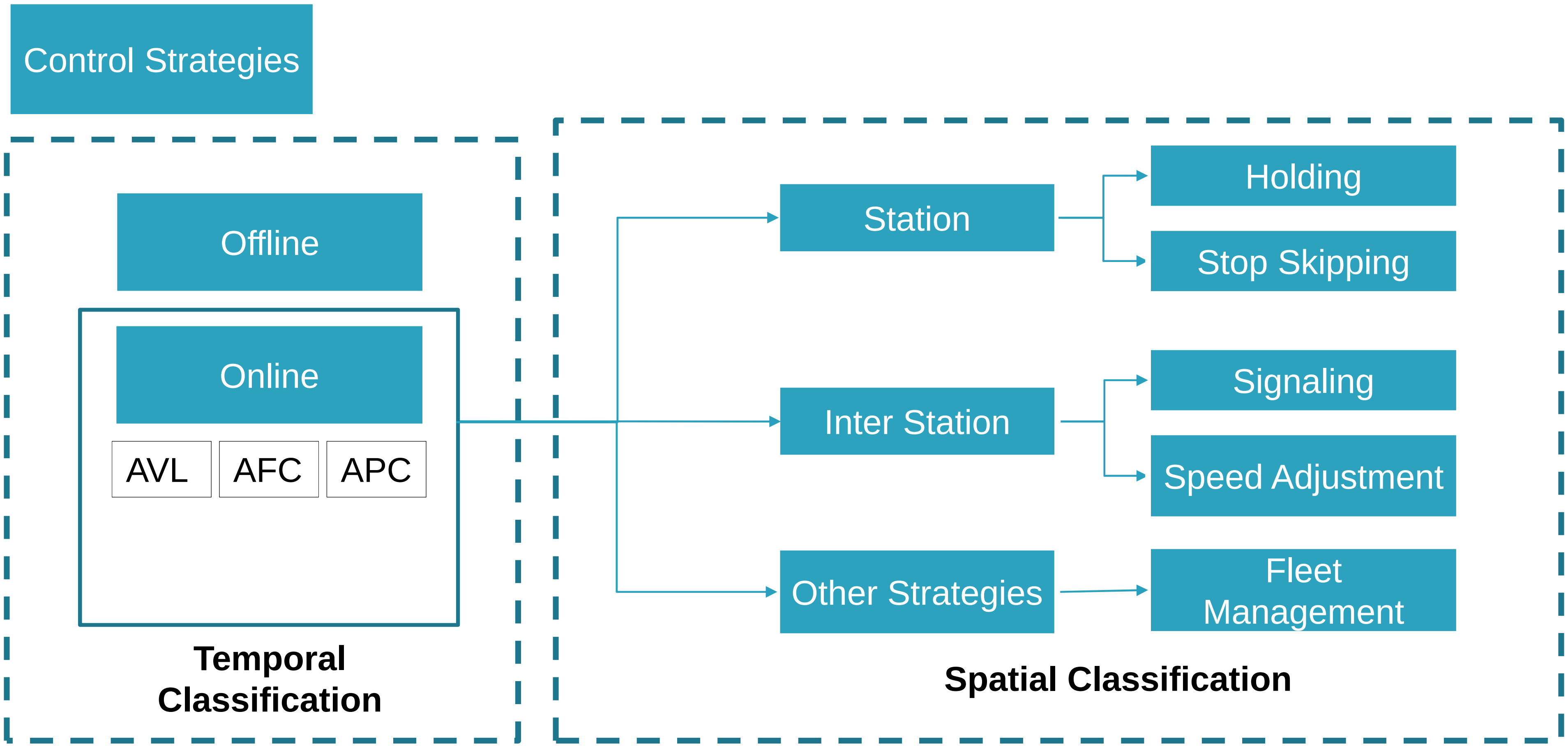
Introduction

- Public transport services are confronted with high variability, coming from:
  - Travel times;
  - Passenger demand.
- Irregular services can lead to:
  - Bunching;
  - Long waiting time and queueing at stops;
  - Overcrowded vehicles;
  - Poor management of available resources.
- **Main Objective**: Maintain regularity and respond to inherent stochastic nature of operation



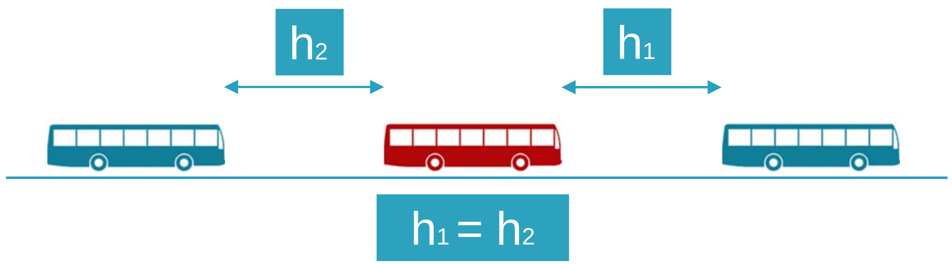
Control Strategies



Holding Strategy

Holding

- Vehicle Based



- Minimization of Travel Cost

$$\min_{w}(Travel\ Time) = [Waiting\ Time + In\ vehicle\ Time + \cdots]\ s.t.\ Capacity\ Constraints, \ldots$$

Headway Based Control Accounting for Passenger Travel Cost

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Holding Criterion

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Main objective: Minimize the additional time spent due to holding

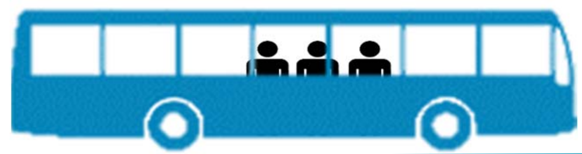
Waiting Time (WT) : The additional waiting time due to holding passengers at the current and the downstream stops will experience.

In Vehicle Time (IVT): The additional delay passengers on board experience due to holding

Weighted Travel Time (TT):

$$\mathrm{TT_k} = 2 * \mathrm{WT_k} + \mathrm{IVT_k}$$

Waiting Time



In Vehicle Time

Holding criterion

Holding Criterion:

- $w_k = \max\left\{\frac{(AT_{k+1}-AT_k)-(AT_k-AT_{k-1})}{2} - \frac{L_k}{4\sum_{i=j+1}^{N}\lambda_i}, 0\right\}$

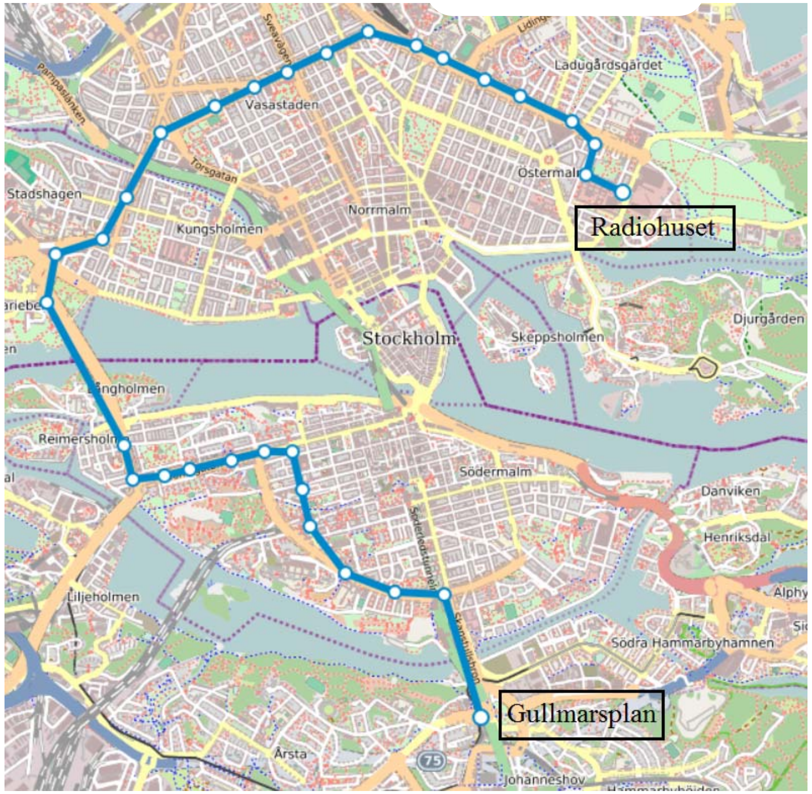
Consists of:

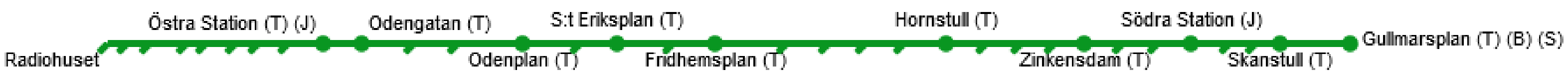
- Even Headway Term
- Passenger Ratio

Case study

- Line 4, Stockholm, Sweden;
- One of the four trunk lines;
- Frequency based;
- High passenger demand;
- Connections with other pt modes;
- Real time information available.

- Comparison with the real time strategy currently used
- Tested for 3 different demand levels





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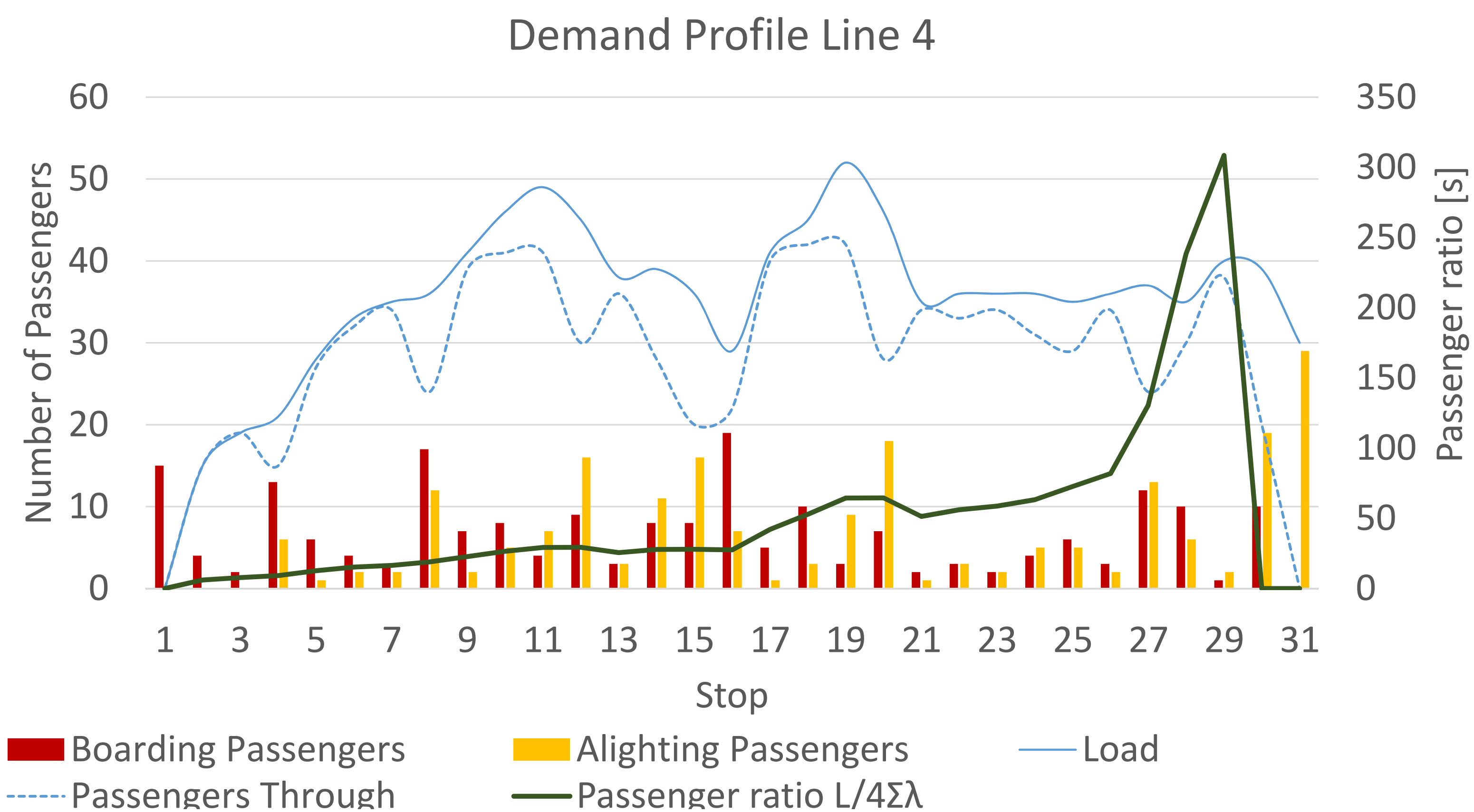
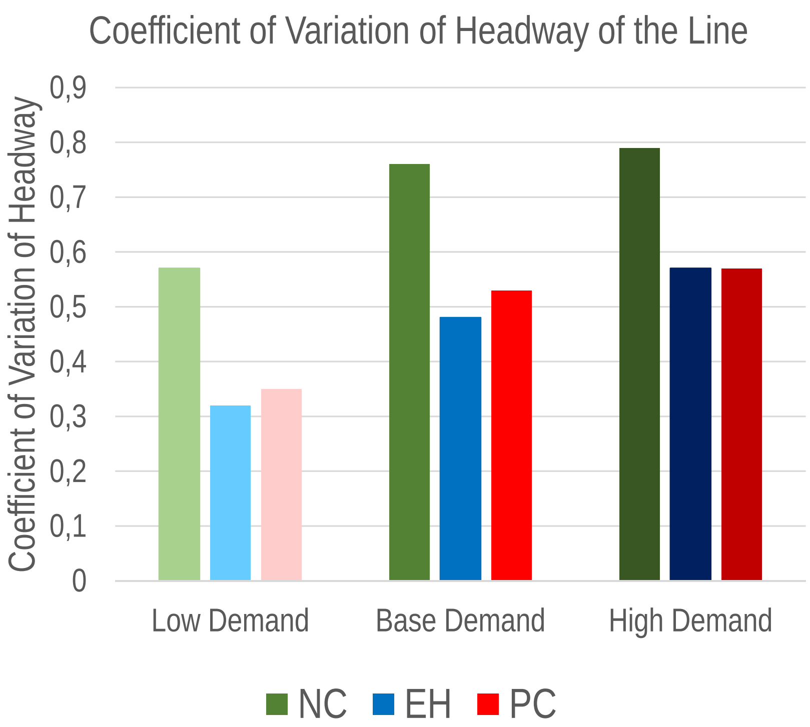
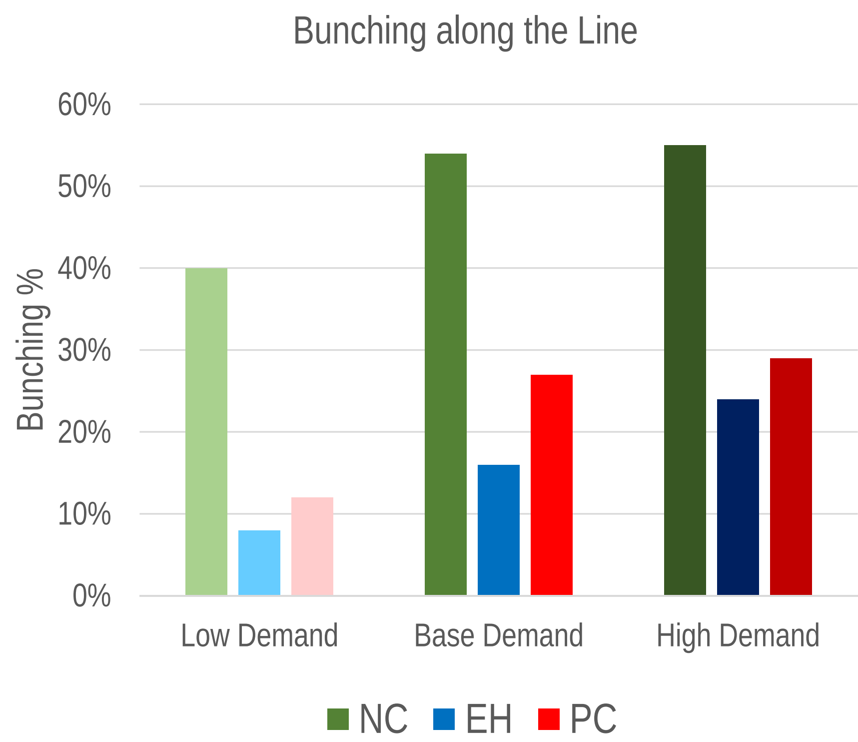
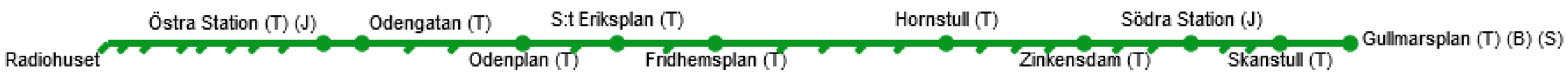
Demand Profile



Results:
Key Performance Indicators - Regularity







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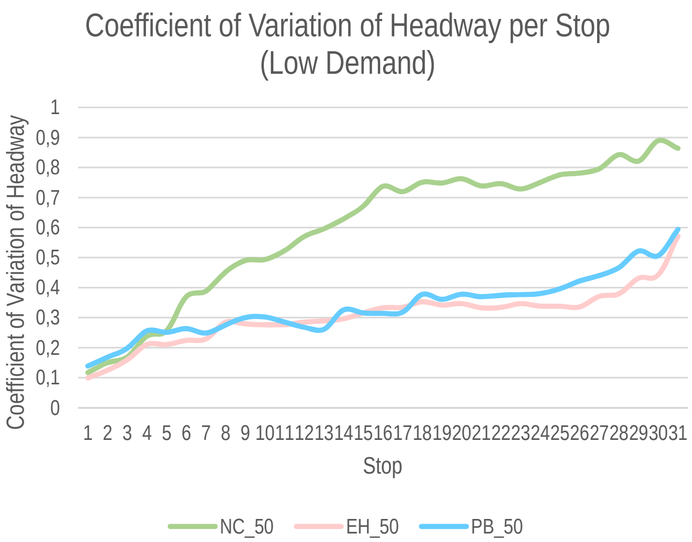
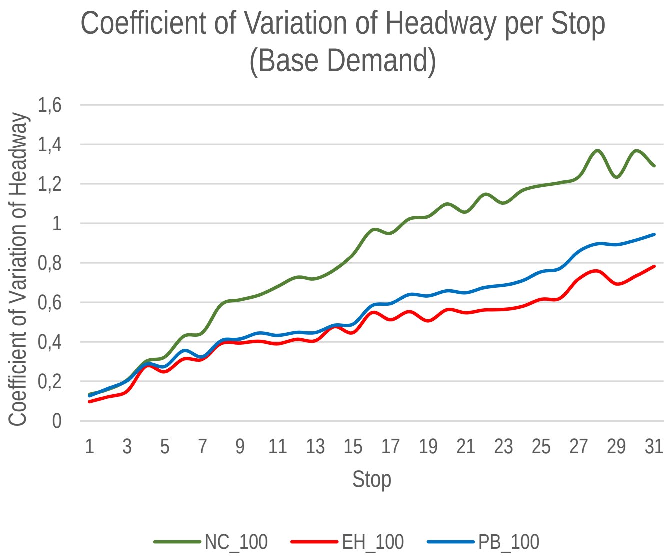
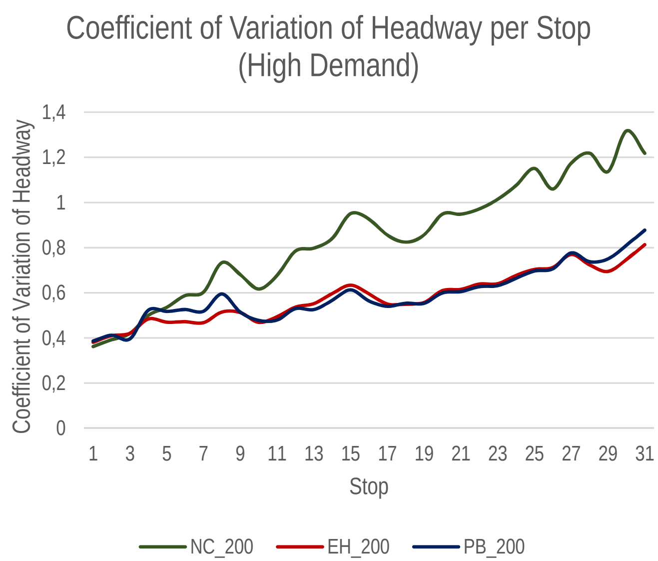
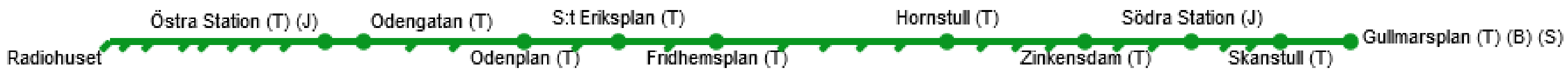
Coefficient of Variation of Headway per Stop









Results: Travel Time in Route Segments

	First half of the route			Second half of the route		
	Average waiting time per passenger (sec)	Average in vehicle delay per passenger (sec)	Average weighted time per passenger (sec)	Average waiting time per passenger (sec)	Average in vehicle delay per passenger (sec)	Average weighted time per passenger (sec)
NC_50	176	102	451	213	98	524
EH_50	155	107	418	160	105	425
PC_50	154	106	414	159	103	422
NC_100	190	116	495	297	109	702
EH_100	164	122	451	189	121	499
PC_100	167	122	456	199	118	515
NC_200	190	146	526	259	131	650
EH_200	174	151	499	185	140	509
PC_200	170	150	490	183	138	503

Conclusions

- **Main contribution:** A headway based rule that regulates headway between consecutive vehicles accounting for the passengers affected by the additional time assigned.

- PC performs similarly to EH with less holding time for **high demand**;

- Holding time is applied mostly at the **beginning of the route**;

Real Time Holding Strategies for Multiple Lines

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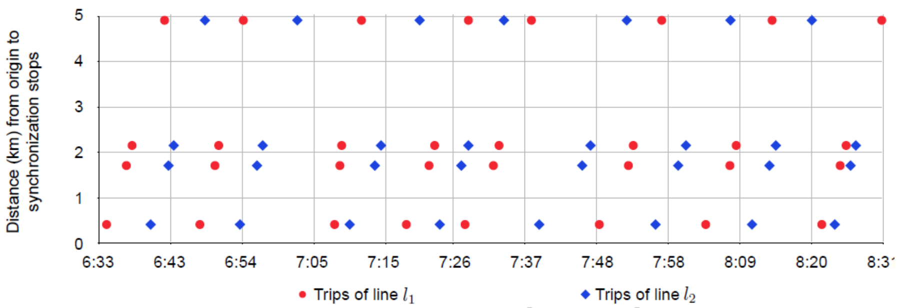
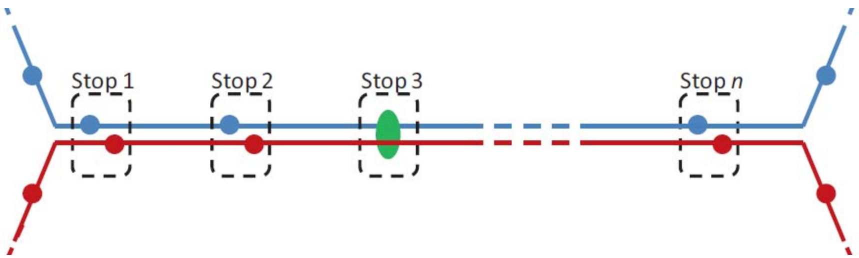
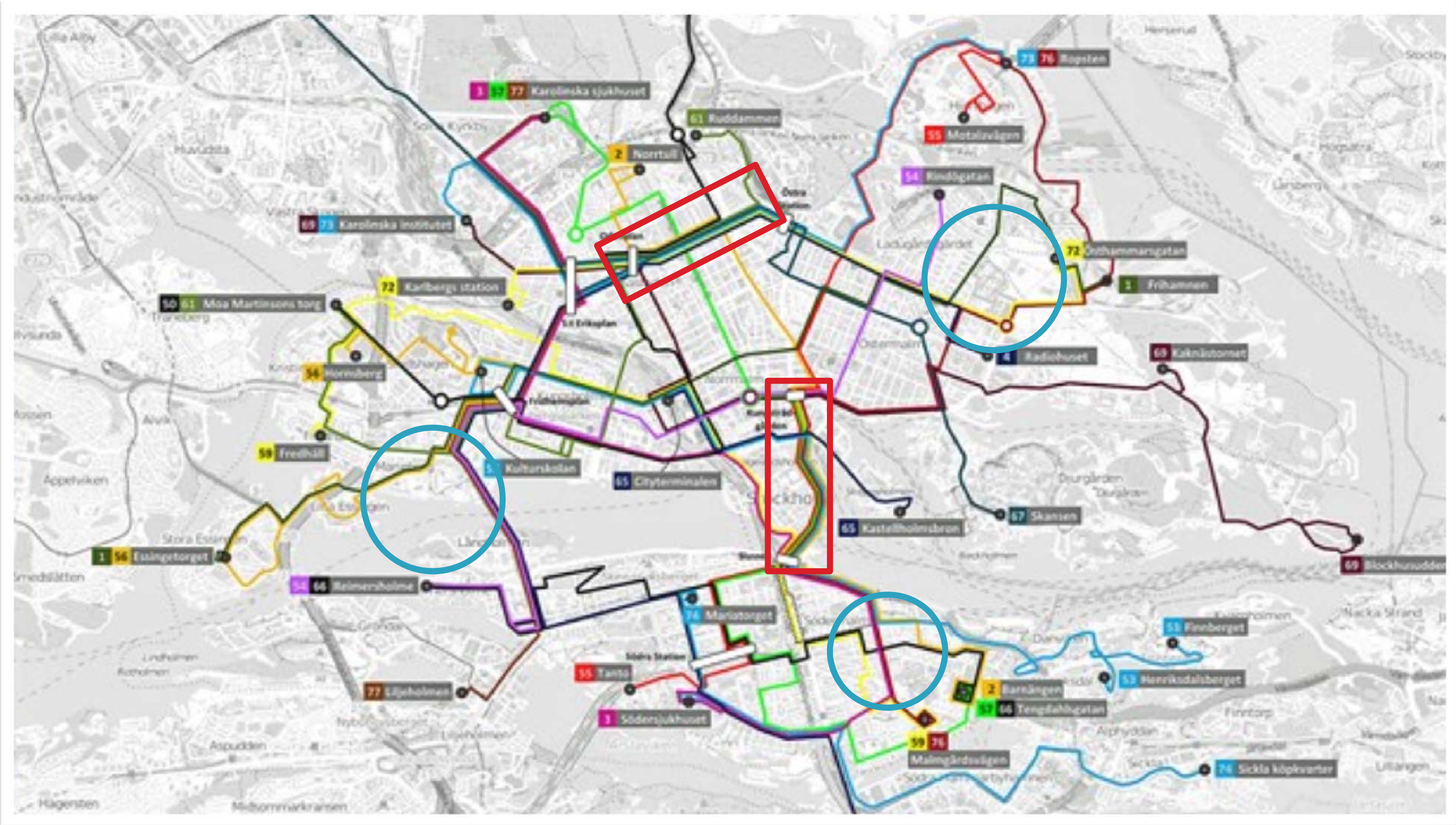
Controlling Multiple Lines

- Coordination between **different modes and lines** to reduce operator cost;
- Control strategies have mostly focused on **transfer coordination** of transferring hubs;
- Recently,
  - **Offline:** Timetable optimization;
  - **Online:** Holding on common route segments, Comparison between scheduled based approaches and frequency based and between headways (line or corridor).





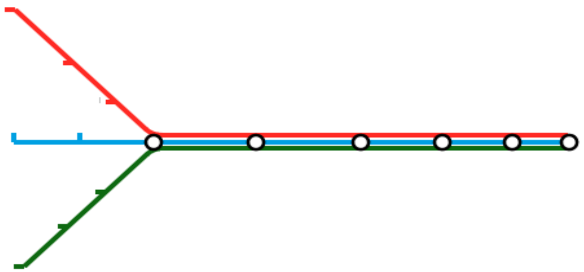
Defining the characteristics of lines with common route segments



Classification of the different networks with multiple lines

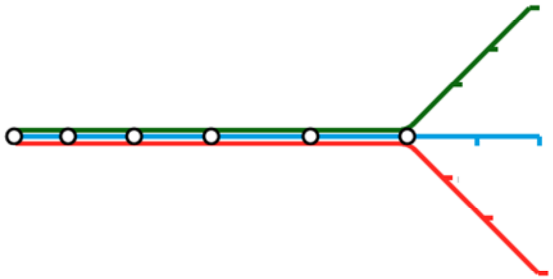
"MERGING FORK" NETWORK

- Lines merge after a specific point;
- Passengers on corridor are satisfied by all lines;
- No transfers.



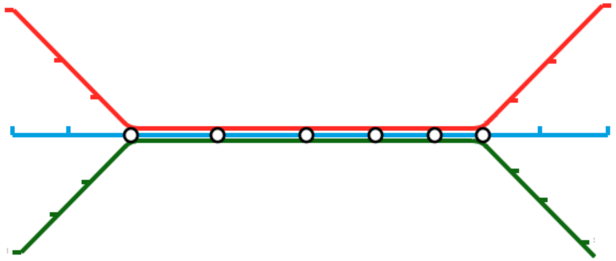
"DIVERGING FORK" NETWORK

- Lines split after a specific point;
- Passengers seeking for the bus that satisfies their final destination;
- No transfers.



"DOUBLE FORK" NETWORK

- Lines merge and split;
- Combines characteristics of "Fork" and "Inversed Fork";
- Transfers at common part.



Holding Criteria for Multiple Line Networks

- Maintain regularity in all different network segments;
- Benefit from the joint frequency at the common part;
- Account for the passenger cost and the different behavior of the passengers at the different part;
- Main objective: Optimize the additional travel time (waiting and in vehicle time) due to holding.
- Criteria vary according to the type of network and the type of stop;

Branches

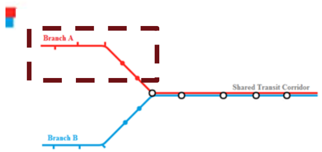
Passengers can board to every vehicle arriving at the stop and gradually vehicles from both lines should make the transition from branch to corridor.

Holding Criterion:

$$w_k = \max\left\{\left(\frac{\theta_1 + u_1}{\sum(\theta+u)}\right)\frac{[(ET_{k+1}-ET_k)-(ET_k-ET_{k-1})]}{2} + \left(\frac{\theta_2 + u_2}{\sum(\theta+u)}\right)\frac{[(\widetilde{ET}_{k+1}-\widetilde{ET}_k)-(\widetilde{ET}_k-\widetilde{ET}_{k-1})]}{2} - \frac{L_k}{4\left(\sum_{m=j}^{N_b}\sum_{n=m+1}^{N}\lambda_{m,n} + \sum_{m=N_b+1}^{N}\sum_{n=m+1}^{N}\lambda_{m,n}\right)}, 0\right\}$$

Demand: $\theta_1 = \frac{\sum_{m=j}^{N_b}\sum_{n=m+1}^{N}\lambda_{m,n}}{\left(\sum_{m=j}^{N_b}\sum_{n=m+1}^{N}\lambda_{m,n}+\sum_{m=N_b+1}^{N}\sum_{n=m+1}^{N}\lambda_{m,n}\right)}$ and $\theta_2 = 1 - \theta_1$

Distance: $u_1 = \frac{1}{\text{merging}-j}$ and $u_2 = 1 - u_1$



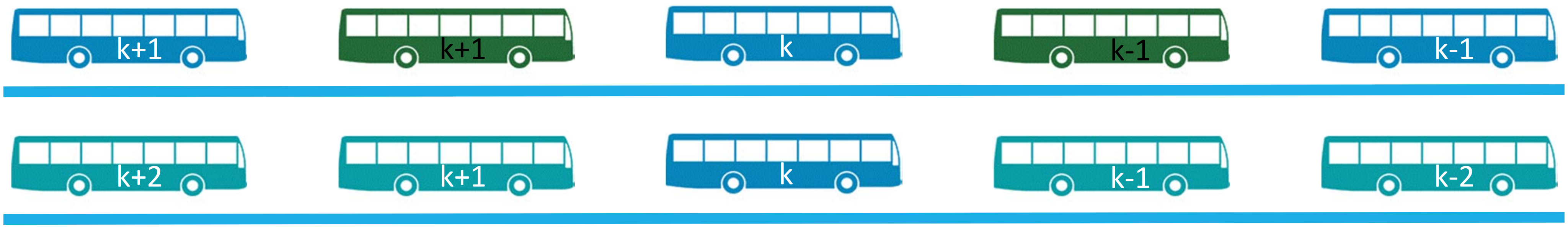
n stops

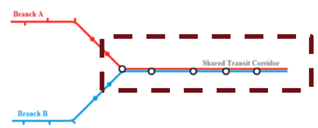
Merging Fork Criteria:
Shared Transit Corridor

Trunk

- Passengers are served by every bus serving the stop regardless the line
- Holding Criterion:

$$w_k = \max\left\{\frac{[(ET_{k+1} - ET_k) - (ET_k - ET_{k-1})]}{2} - \frac{L_k}{4\sum_{m=j}^{N}\sum_{n=m+1}^{N}\lambda_{m,n}}, 0\right\}$$



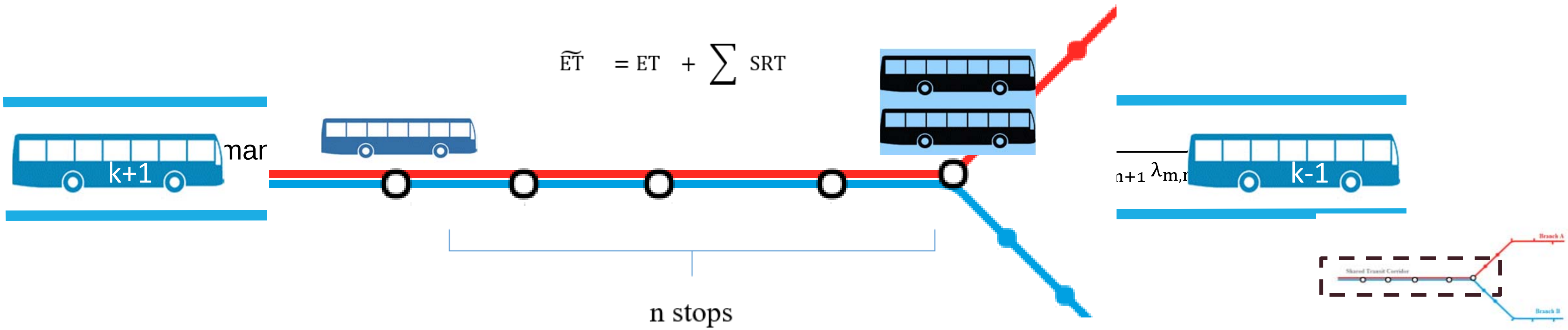


Trunk

Vehicles of lines interact and there are passengers seeking for a specific line

- Holding Criterion:

$$w_k = \max\left\{\theta_1 \frac{[(ET_{k+1} - ET_k) - (ET_k - ET_{k-1})]}{2} + \theta_2 \frac{[(ET_{Ak+1} - ET_{Ak}) - (ET_{Ak} - ET_{Ak-1})]}{2} + \theta_3 \frac{[(\widetilde{ET}_{Ak+1} - \widetilde{ET}_{Ak}) - (\widetilde{ET}_{Ak} - \widetilde{ET}_{Ak-1})]}{2} - \frac{L_k}{4\left(\sum_{m=j}^{N_c}\sum_{n=m+1}^{N_c}\lambda_{m,n} + \sum_{m=j}^{N_c}\sum_{n=m+1}^{N}\lambda_{m,n} + \sum_{m=j}^{N}\sum_{n=m+1}^{N}\lambda_{m,n}\right)}, 0\right\}$$



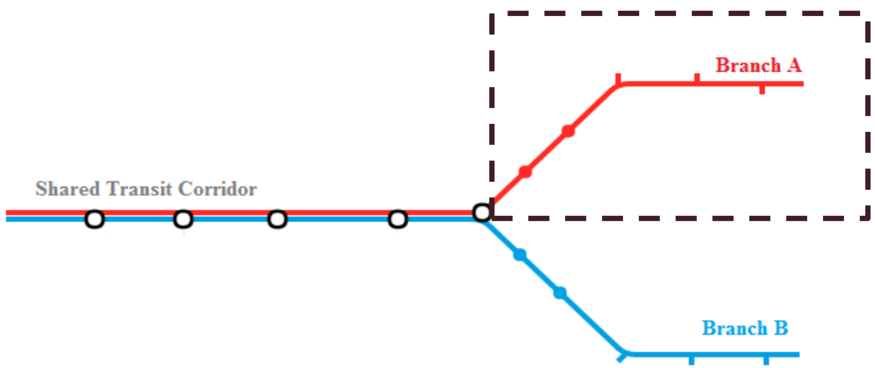
Diverging Fork Criteria: Branches

Branches

No interaction with other line, single line criterion can be used

Holding Criterion:

$$w_k = \max\left\{\frac{[(ET_{k+1} - ET_k) - (ET_k - ET_{k-1})]}{2} - \frac{L_k}{4\sum_{m=j}^{N}\sum_{n=m+1}^{N}\lambda_{m,n}}, 0\right\}$$



In Progress…

- Implementing the criteria;
  - BusMezzo
- Test them for a case study including high frequency lines;
- Evaluate the performance;
  - Single Line performance;
  - Joint operation performance;
- Compare different operation schemes;
  - Independence;
  - Cooperation;
- Extend the criteria to include transferring cost in the common route segments.
  - Where to transfer?
  - Favor regularity or direct transfers?


Thank you very much
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