Real Time Holding Control for Multiline Networks

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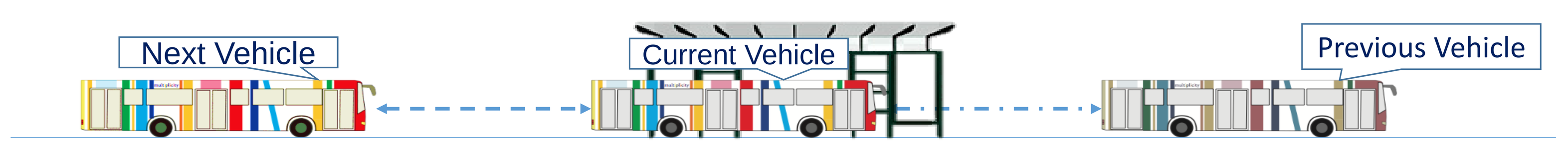
Abstract: We introduce a rule based multiline holding criterion for regularity in branch and trunk networks accounting for all passenger groups. On the shared transit corridor, we consider synchronization at the merging or the diverging stop. The decision between holding for regularity or synchronization is taken by comparing the expected passenger cost of each control action. The proposed criterion is tested through simulation in a synthetic double fork network with different shares of transferring passengers, control schemes for regularity and synchronization. The results show that multiline control outperforms the state of the art schemes at the network level, stemming from benefits occurring at the first part of the route and the shared transit corridor and a 3.5% more stable joint headway compared to the other schemes. Additionally, it is advised to perform the synchronization at the diverging stop, as it proves to result in a more stable transferring time equal to the joint frequency of the corridor while reducing the transfer time variability up to -42.7%.

Holding Strategy

- Station control strategy ;
- Vehicle is instructed to wait for additional time to maintain evenly spaced headways;
- Current approach: Rule based approach;
  - Regulate departure of current vehicle based on the headway from the preceding and the succeeding vehicle;
  - Limit the maximum holding time s.t. a share of the planned headway .



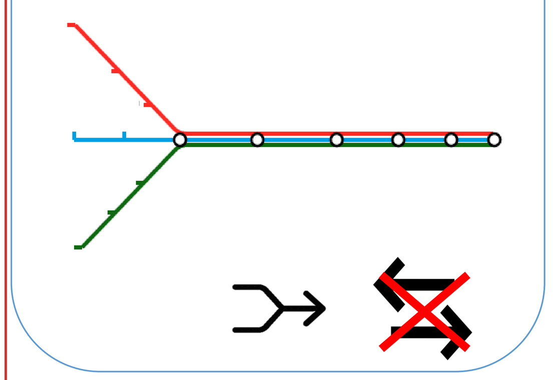
Contribution: We apply a multiline holding criterion for regularity in branch-and-trunk networks consisting of branches prior and after a shared transit corridor. In addition, at the first and the last common stop we combine the regularity criterion with a holding criterion for synchronization.

- we assess the performance of multiline control compared to single line control and its effect on the cost of every passenger group; and
- we explore on which common stop synchronization can be feasible and the resulting impact on the regularity of the individual lines.

Trunk and Branch Networks

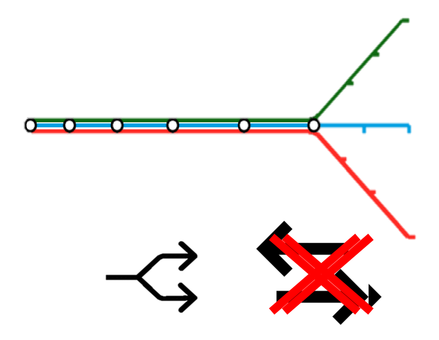
MERGING FORK

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



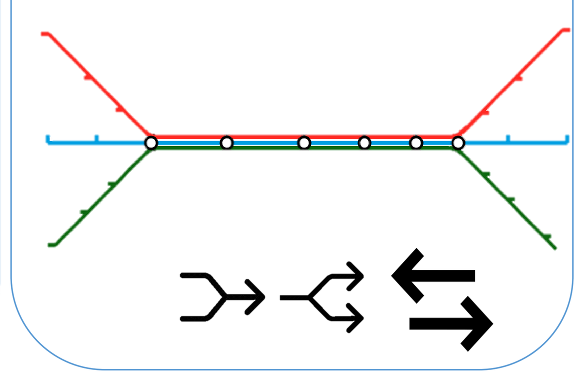
DIVERGING FORK

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



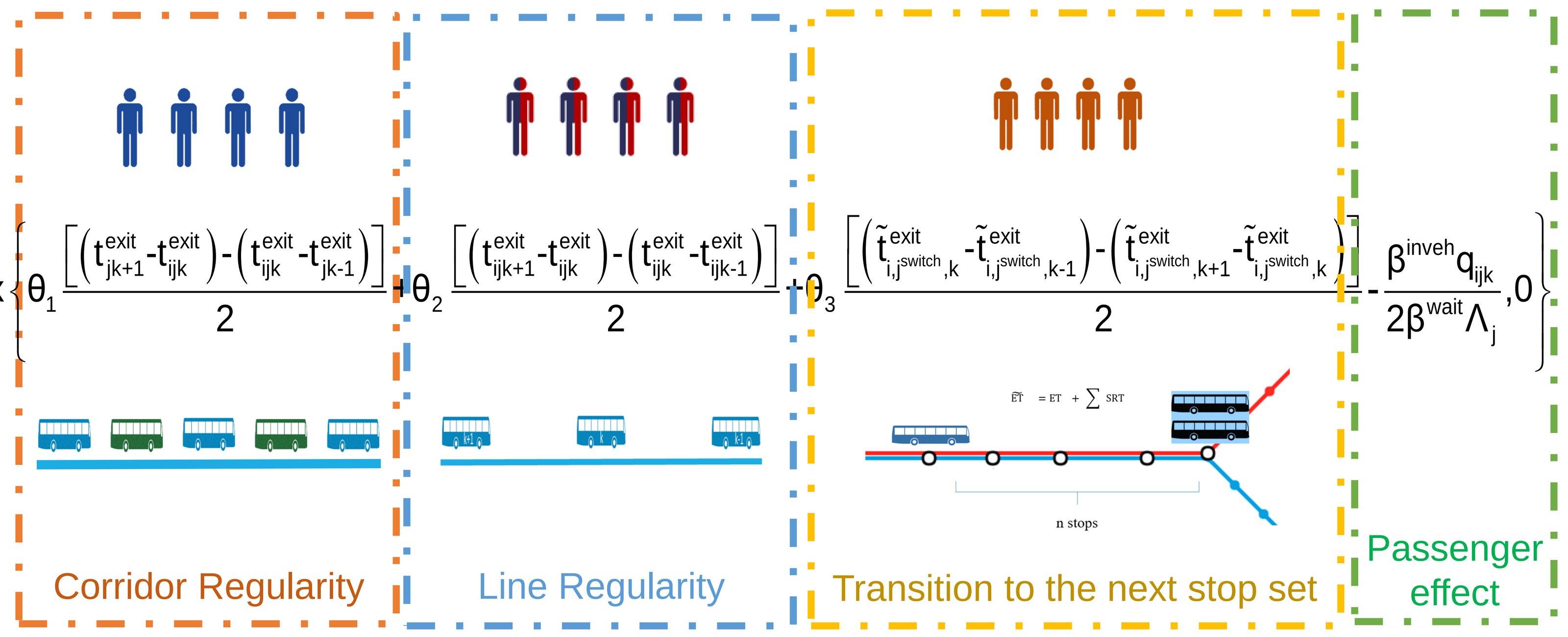
DOUBLE FORK

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

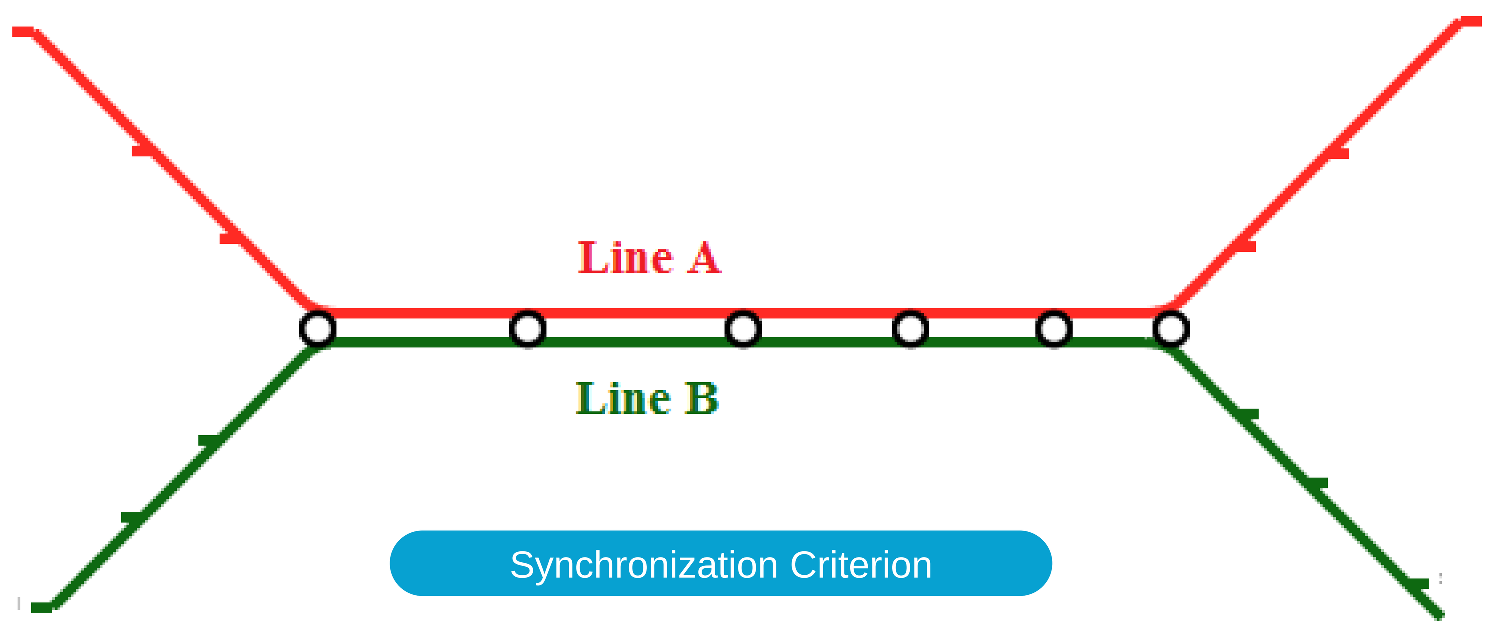


Methodology

Regularity Criterion



$$\max\left\{\theta_1\frac{\left[\left(t^{exit}_{jk+1}-t^{exit}_{ijk}\right)-\left(t^{exit}_{ijk}-t^{exit}_{jk-1}\right)\right]}{2}+\theta_2\frac{\left[\left(t^{exit}_{ijk+1}-t^{exit}_{ijk}\right)-\left(t^{exit}_{ijk}-t^{exit}_{ijk-1}\right)\right]}{2}+\theta_3\frac{\left[\left(\tilde{t}^{exit}_{i,j^{switch},k}-\tilde{t}^{exit}_{i,j^{switch},k-1}\right)-\left(\tilde{t}^{exit}_{i,j^{switch},k+1}-\tilde{t}^{exit}_{i,j^{switch},k}\right)\right]}{2}-\frac{\beta^{inveh}q_{ijk}}{2\beta^{wait}\Lambda_j},0\right\}$$



Synchronization Criterion

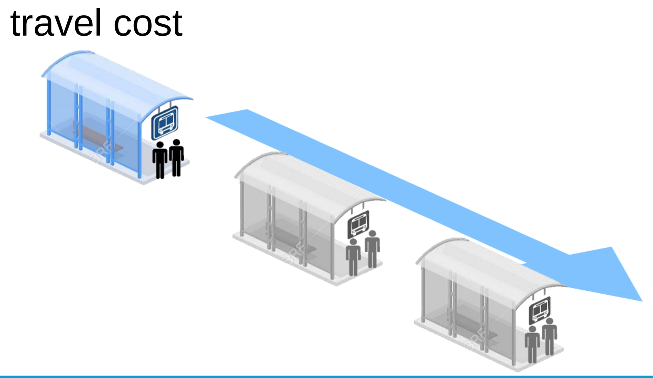
$$t_i^{hold,sync}=\left(\tilde{t}^{arrival}_{i+1}-t^{arrival}_{i}\right)+\tau^{transfer}$$

Regularity vs Synchronization

Select the holding time that yields the lowest total passenger travel cost

$$Pax\_Cost=\beta_{wait}c^{wait}+\beta_{transfer}c^{transfer}+\beta_{held}c^{held}$$

$$t^{hold}=\begin{cases}t^{hold,reg} & Pax\_Cost^{reg}<Pax\_Cost^{sync}\\ t^{hold,sync} & Pax\_Cost^{reg}>Pax\_Cost^{sync}\end{cases}$$

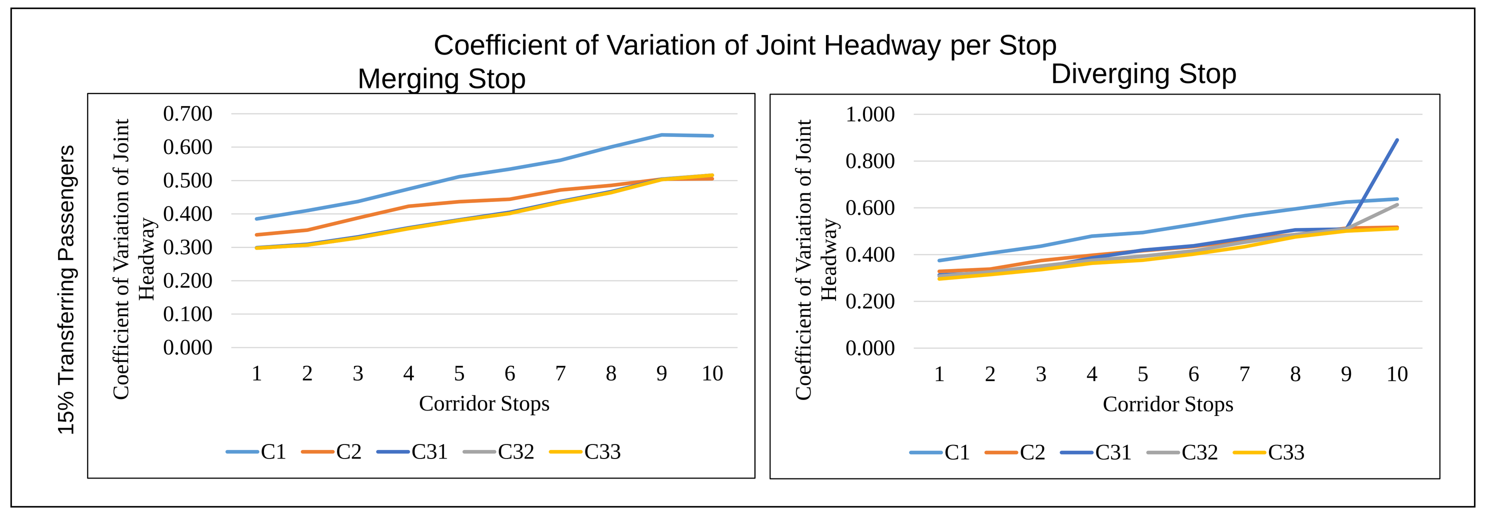


Controller Application

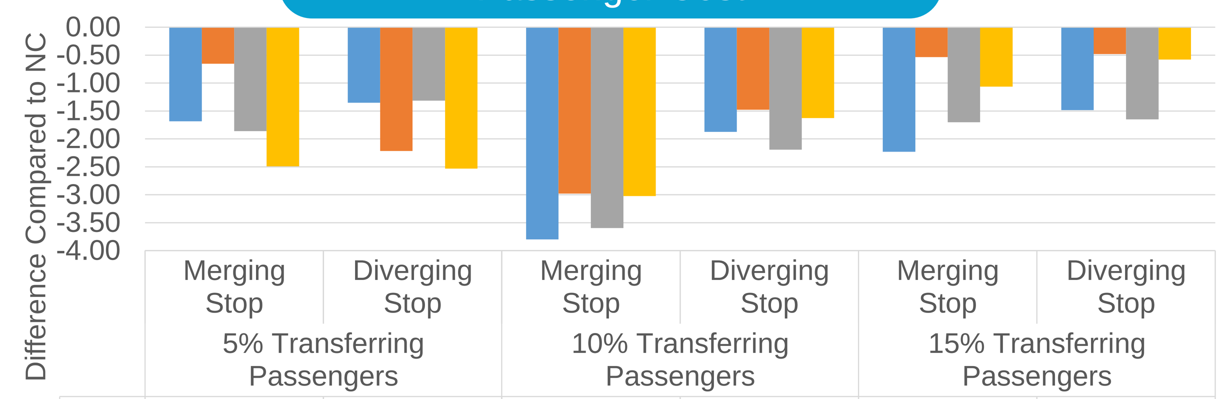
Share of Transferring Passengers	Scenario Name	Synchronization Stop	Control Scheme	Cost Comparison Horizon
5%	S_1C_1	Merging Stop	NC	NA
	S_1C_2		EH	NA
	S_1C_{31}		CPC	One (Current) Stop
10%	S_1C_{32}			Five Stops
	S_1C_{33}			Ten Stops
	S_2C_1	Diverging Stop	NC	NA
15%	S_2C_2		EH	NA
	S_2C_{31}		CPC	One (Current) Stop
	S_2C_{32}			Five Stops
	S_2C_{33}			Ten Stops

Results

Corridor Results



Passenger Cost

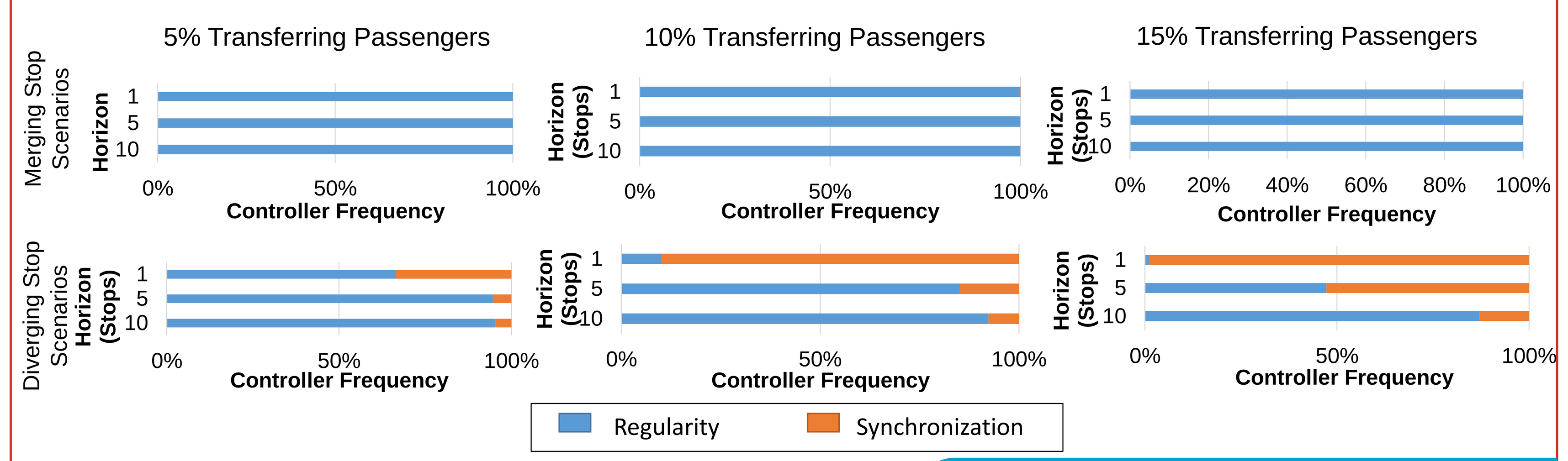


	5% Transferring Passengers – Merging Stop	5% Transferring Passengers – Diverging Stop	10% Transferring Passengers – Merging Stop	10% Transferring Passengers – Diverging Stop	15% Transferring Passengers – Merging Stop	15% Transferring Passengers – Diverging Stop
C2	-1.69	-1.35	-3.80	-1.88	-2.23	-1.49
C32	-0.65	-2.22	-2.98	-1.48	-0.53	-0.48
C33	-1.86	-1.32	-3.60	-2.19	-1.70	-1.65
C31	-2.49	-2.53	-3.02	-1.63	-1.06	-0.58

Transfer Waiting Times

		C1 Average Transfer Time [sec]	C1 St Deviation	C2 Average Transfer Time [sec]	C2 St Deviation	C31 Average Transfer Time [sec]	C31 St Deviation	C32 Average Transfer Time [sec]	C32 St Deviation	C33 Average Transfer Time [sec]	C33 St Deviation
Merging Stop S1	5% Transferring Passengers	287.8	39.7	303.2	42.3	288.6	34.5	295.7	29.1	289.1	30.2
	10% Transferring Passengers	288.5	37.3	291.0	34.7	303.6	30.8	293.2	26.5	307.3	28.2
	15% Transferring Passengers	295.5	42.6	285.3	43.2	299.0	25.4	297.0	26.6	299.1	25.4
Diverging Stop S2	5% Transferring Passengers	291.3	34.5	308.0	43.2	304.5	28.8	318.1	24.7	310.8	26.6
	10% Transferring Passengers	287.1	38.2	286.9	34.7	299.0	30.0	297.5	24.8	301.5	30.0
	15% Transferring Passengers	294.7	38.8	282.6	41.3	295.9	27.9	293.6	26.6	288.9	24.5

Controller Frequency



Key Findings

- Multiline control is beneficial for the network, resulting in a lower overall passenger cost. This result comes from the substantial gains along the shared transit corridor;
- Coordination helps to achieve a joint headway with lower variability prior to the common stop set and this is maintained along the corridor;
- The performance of CPC at the individual line level is not as high as single line control, significant cost reduction with lower in vehicle delay for the lines;
- Synchronization becomes feasible and the dominant choice under a range of demand distribution settings for shorter cost comparison horizons at the diverging;
- Transferring passengers benefit mostly by the low variability of the joint headway and their average transfer time corresponds to the headway of the shared transit corridor.

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