The Bus Rapid Transit Planning Guide, 4th Edition

Volume II: Operations

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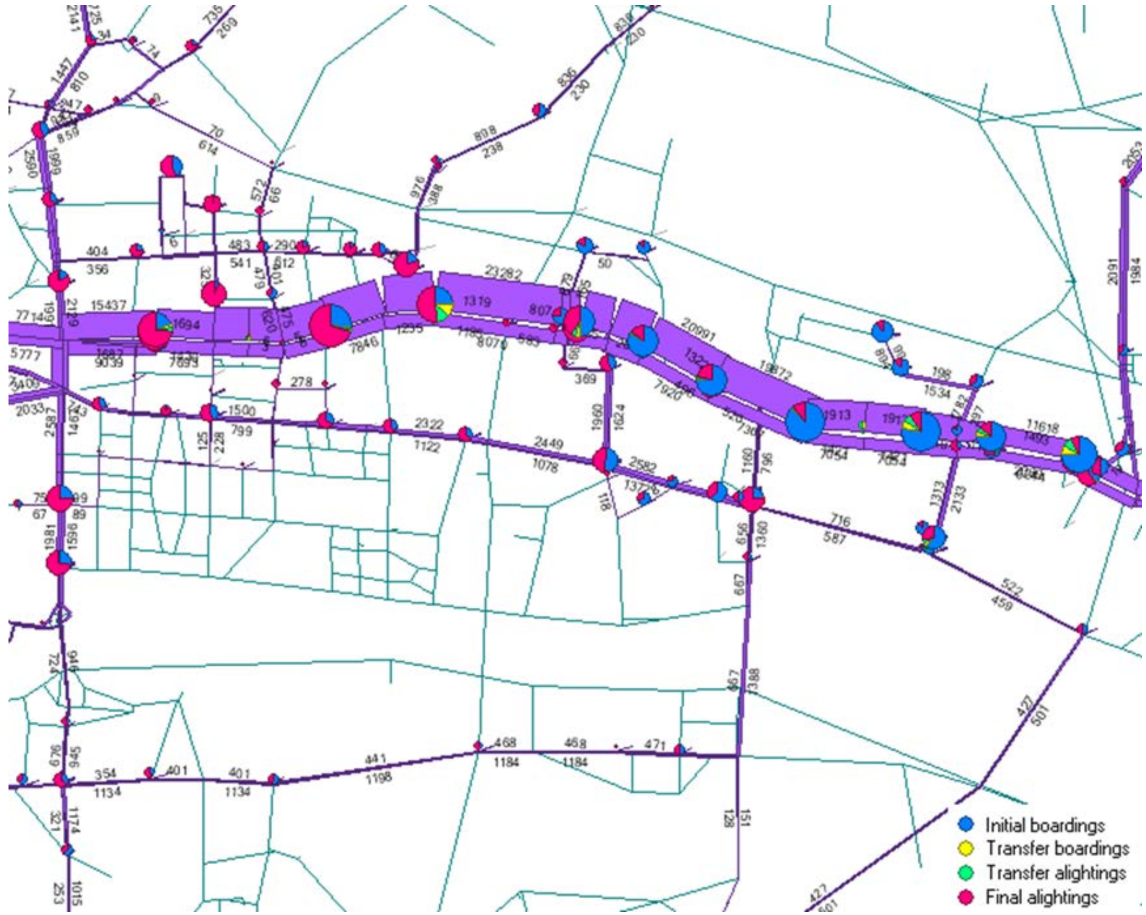
BRT Planning International

CH. 4 DEMAND ANALYSIS

For service planning, we need details about existing services

- Route-by-route boarding and alighting data
- Transfer surveys at high volume transfer points.
- Create a transit OD matrix using ‘fratar’ probability

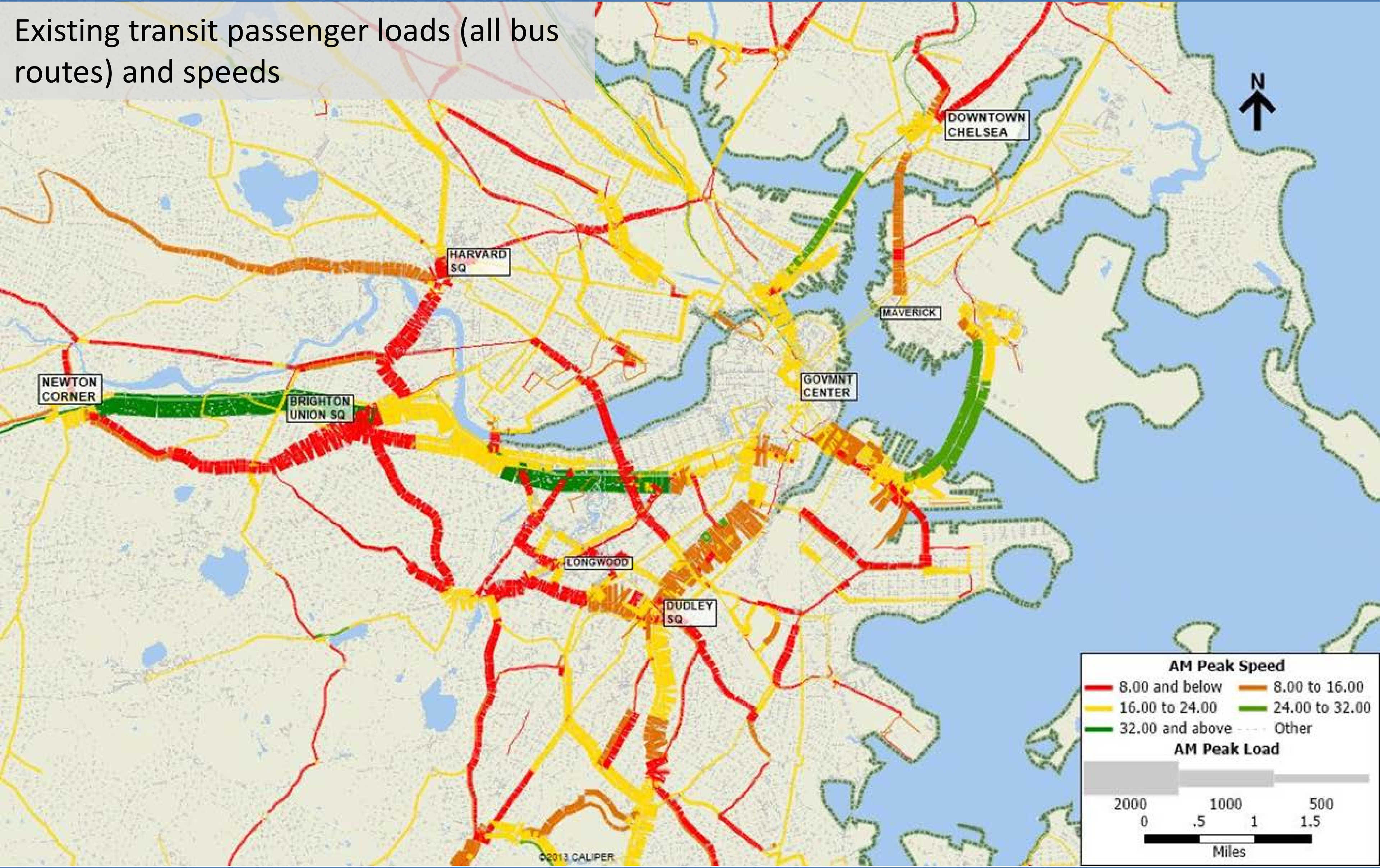
- Reduced emphasis on traditional 4-step modelling
  - Too slow
  - Requires too much data
  - Not accurate at the stop level



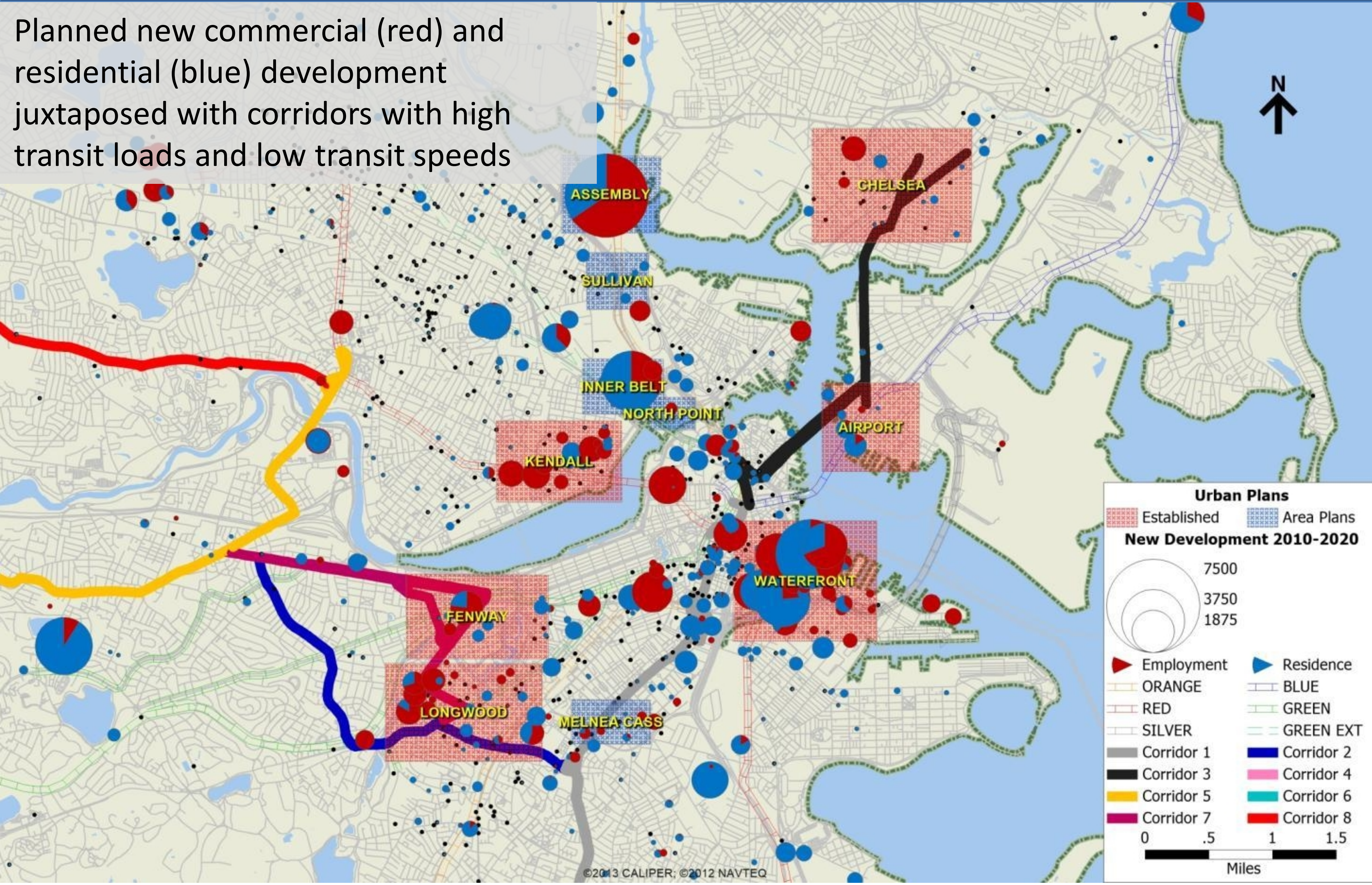
How to decide where to put a BRT Corridor

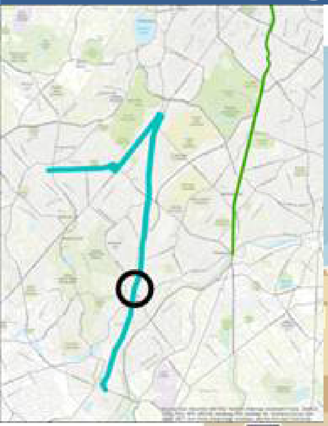
- Existing demand
- Existing transit delay
- Future demand (development approvals and strategic plans)
- Right-of-way (cost, land acquisition)
- Political / Community considerations

Existing transit passenger loads (all bus routes) and speeds



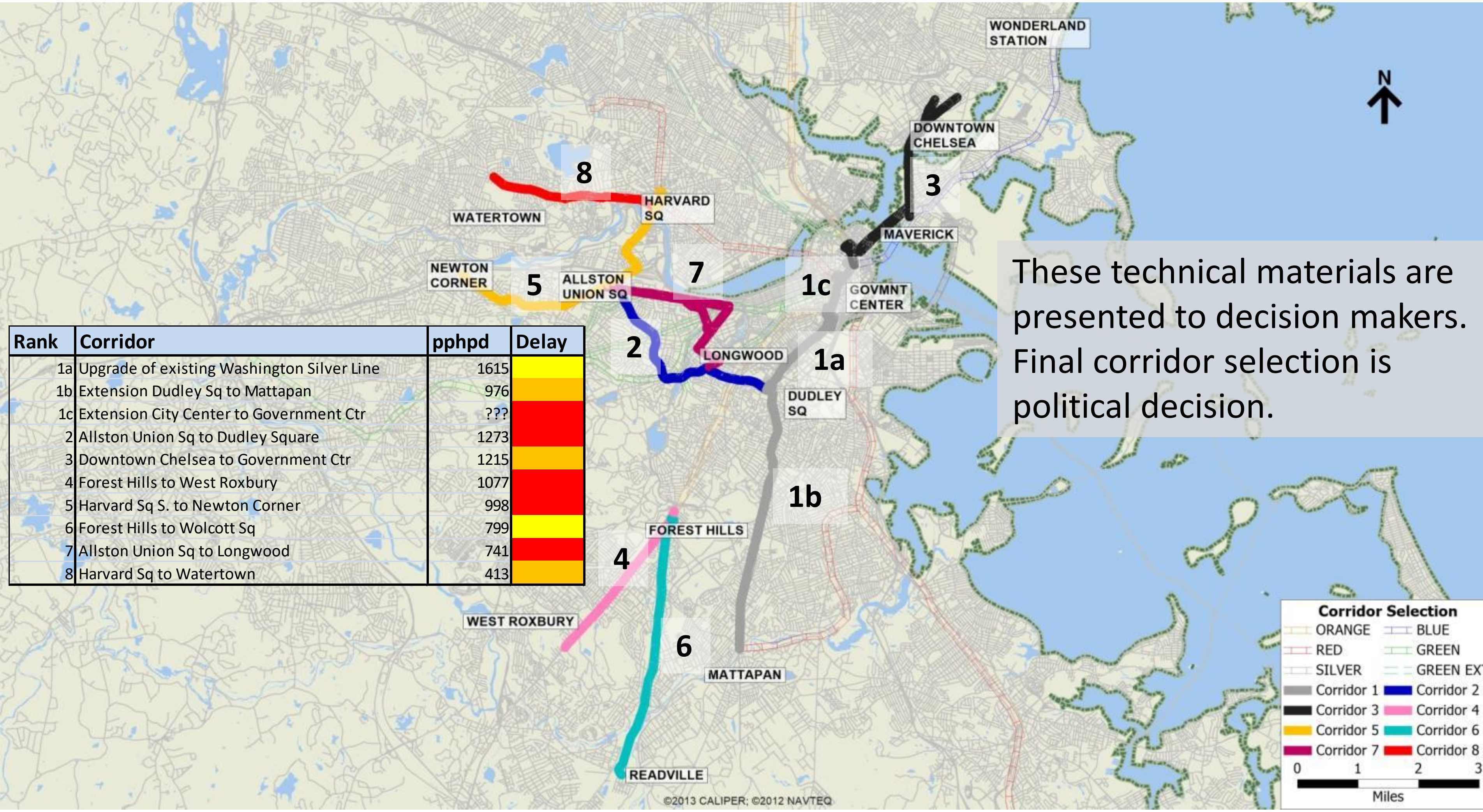
Planned new commercial (red) and residential (blue) development juxtaposed with corridors with high transit loads and low transit speeds





How easy is it to put BRT on this corridor?

Cost and political ease



Rank	Corridor	pphpd	Delay
1a	Upgrade of existing Washington Silver Line	1615	
1b	Extension Dudley Sq to Mattapan	976	
1c	Extension City Center to Government Ctr	???	
2	Allston Union Sq to Dudley Square	1273	
3	Downtown Chelsea to Government Ctr	1215	
4	Forest Hills to West Roxbury	1077	
5	Harvard Sq S. to Newton Corner	998	
6	Forest Hills to Wolcott Sq	799	
7	Allston Union Sq to Longwood	741	
8	Harvard Sq to Watertown	413	

These technical materials are presented to decision makers. Final corridor selection is political decision.

CH. 6: SERVICE PLANNING

6.1 Introduction
6.2 Basic Data Collection
6.3 Basic Service Planning Concepts
6.4 Optimizing Vehicle Size and Fleet Size
6.5 Determining Which Routes to Include Inside BRT Infrastructure
6.6 Direct Services, Trunk-and-Feeder Services, or Hybrids
6.7 Deciding on Stop Elimination and Express Services
6.8 Creating New Routes and Combining Old Routes
6.9 Pulling Services onto a BRT Trunk Corridor from a Parallel Corridor

6.3 BASIC SERVICE PLANNING CONCEPTS

Peak Hour:
The hour that carries the most passengers.

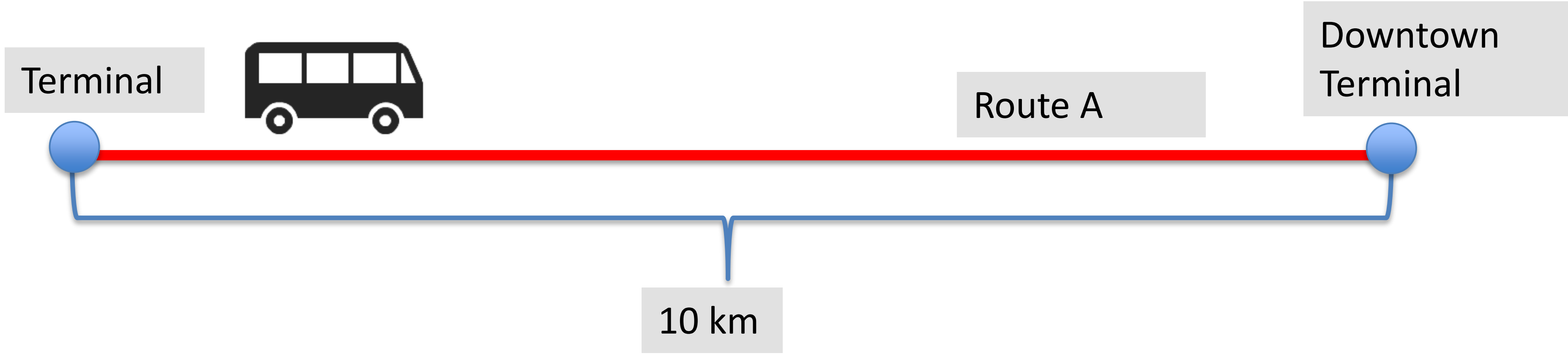
Determining the Peak Hour:
From boarding and alighting data on all routes that use the corridor, pick the hour with the highest aggregate loads at the highest demand part of the route

15 Minute Headway	
Time	Loads per bus on the Critical Link
6:00 a.m.	15
6:15 a.m.	21
6:30 a.m.	31
6:45 a.m.	51
7:00 a.m.	63
7:15 a.m.	69
7:30 a.m.	67
7:45 a.m.	66
8:00 a.m.	53
8:15 a.m.	45
8:30 a.m.	34
8:45 a.m.	32
9:00 a.m.	21
9:00 a.m.	21
9:15 a.m.	19
9:30 a.m.	35
9:45 a.m.	24
10:00 a.m.	29
10:15 a.m.	25
10:30 a.m.	25

Deriving Travel Times from Speeds: Bus and BRT

$$\text{travel time} = \frac{\text{travel distance}}{\text{average speed}}$$

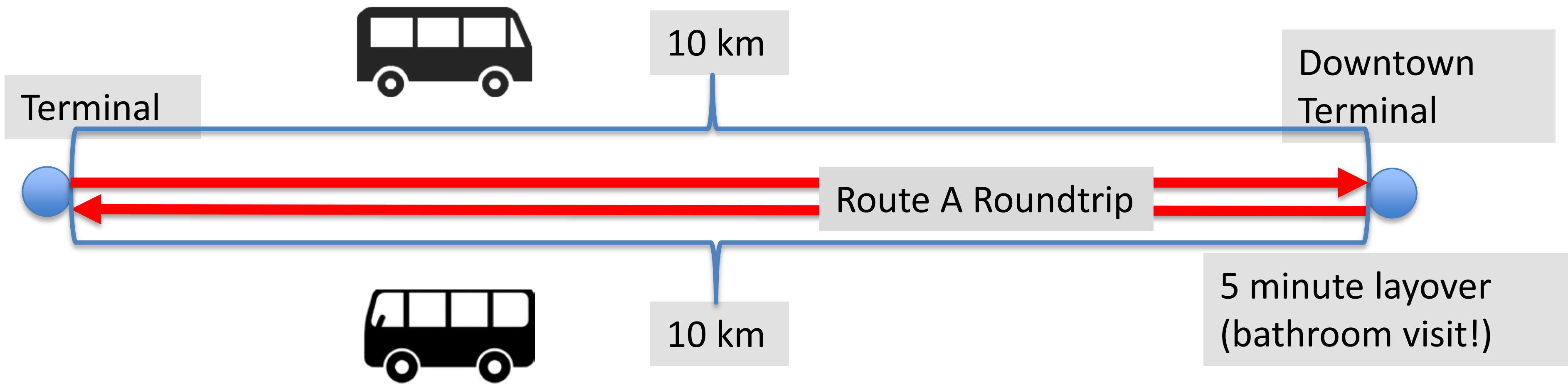
Current speed, Route A bus = 10 kph
Planning speed, Route A BRT = 25 kph



Route A **bus** Travel Time: 10 km / 10 kph = 1 hour (60 minutes)
Route A **BRT** Travel Time: 10 km / 25 kph = 0.4 hours (24 minutes)

Cycle Time:
The time it takes for a bus to make a roundtrip.

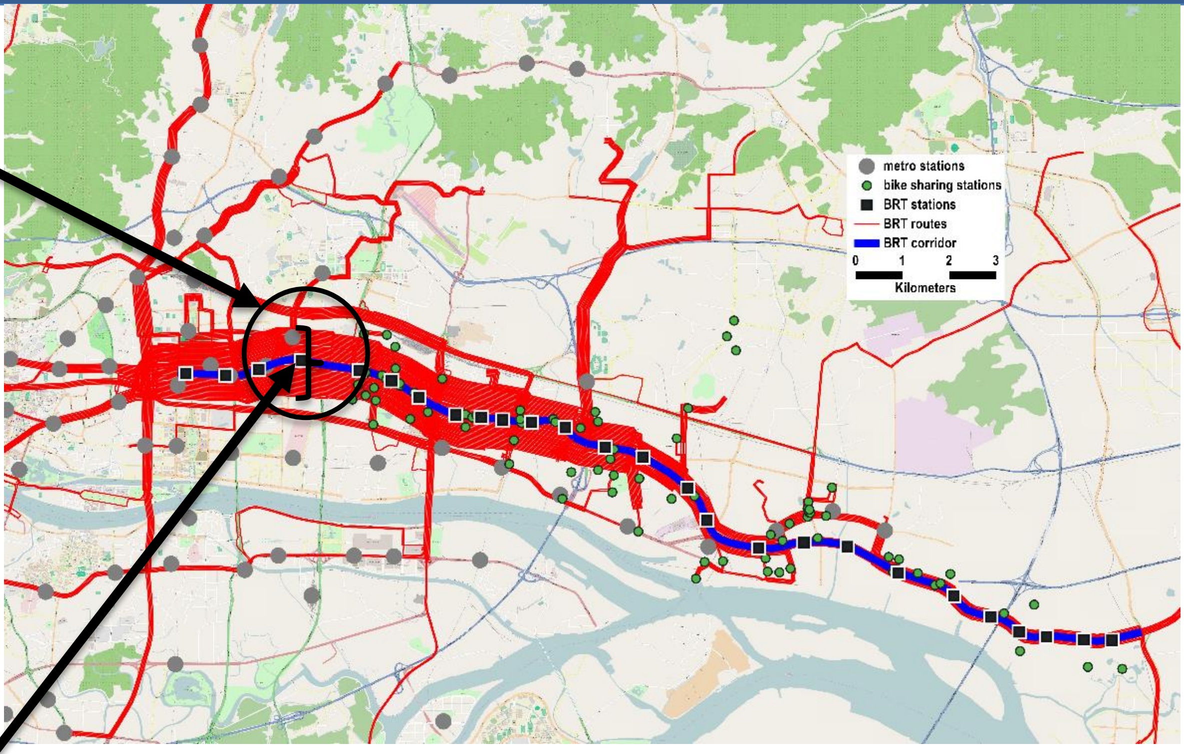
Current speed, Route A bus = 10 kph
Planning speed, Route A BRT = 25 kph



Route A **bus** Cycle Time = (10 km * 2) /10 kph + 5 minute (layover) = 125 minutes
Route A **BRT** Cycle Time = (10 km * 2) / 25 kph + 5 minute (layover) = 53 minutes

6.3 BASIC SERVICE PLANNING CONCEPTS

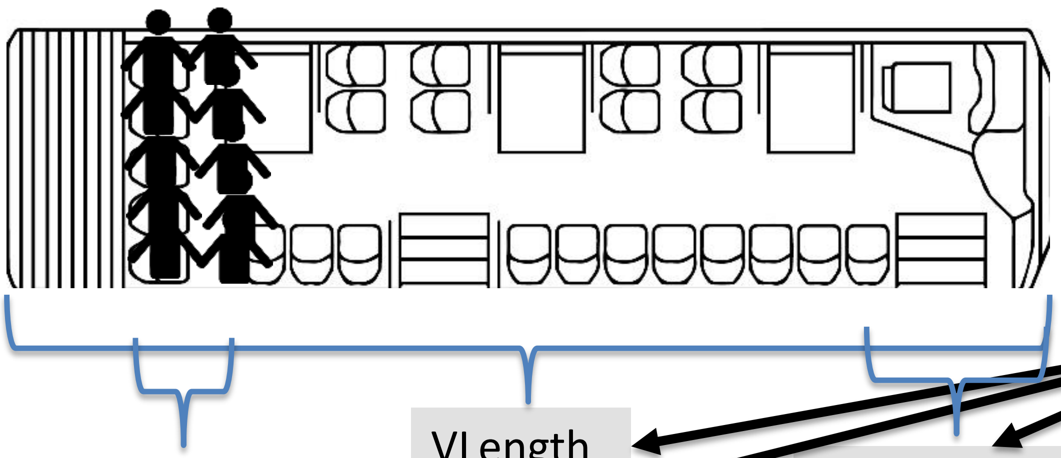
Critical Link:
The section of the corridor with the highest loads during the peak hour



Determining the Critical Link:
Add up the loads on each route for each link of the planned BRT corridor

Max Load:
The total passenger load on the critical link during the peak hour

6.3 BASIC SERVICE PLANNING CONCEPTS



Vehicle Capacity:
# of people that fit on a bus.

Calculating Vehicle Capacity (VSize) (meters):
VSize = (VLength – 3) * 10

Load factor:
% of Vehicle Capacity to make for a reasonably comfortable trip, used for planning purposes. Usually 85%.

Table 6.6: Vehicle Capacity and Load Factors for Typical BRT Vehicles

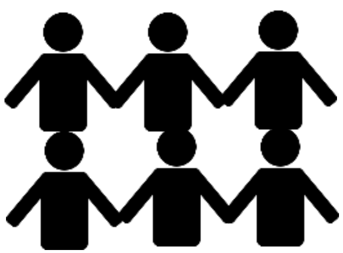
Type	Vehicle Length (meters)	Capacity (customers)	Capacity w Load Factor
Minibus	9	60	51
Bus	12	90	77
Articulated	18	150	127
Bi-Articulated	25	220	187

Frequency:

Buses in the peak hour, peak direction.

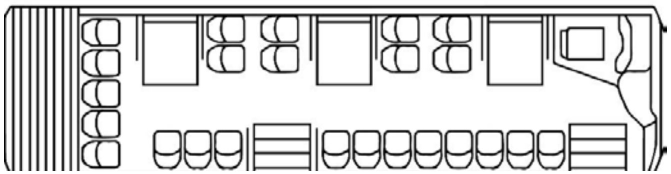
Determining Frequency for Planned BRT Corridor:

Divide the existing Max Load by the BRT Vehicle Size, applying a reasonable load factor

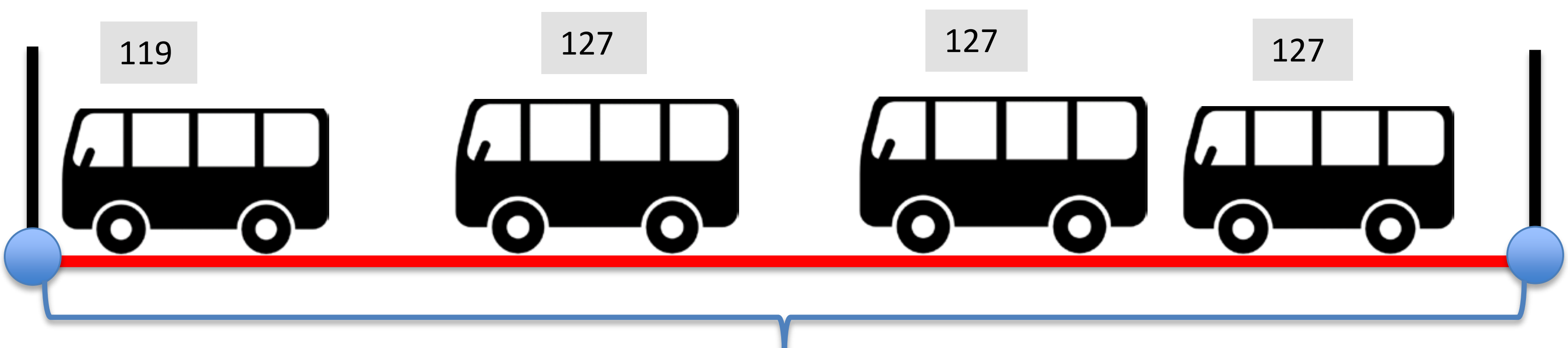


Existing MaxLoad = 500

$$Freq = \frac{MaxLoad}{VSize * LoadFactor}$$



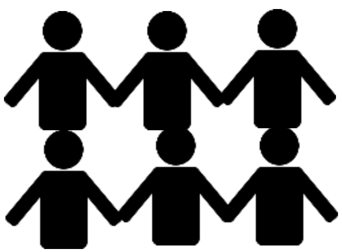
18 meter BRT Vehicle Capacity, 85% Load Factor = 127



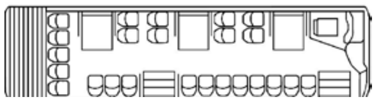
Frequency for Planned BRT Corridor = **3.9**, round up to **4**

6.3 BASIC SERVICE PLANNING CONCEPTS

But if you design for 9-meter vehicles rather than 18-meter vehicles, for example…

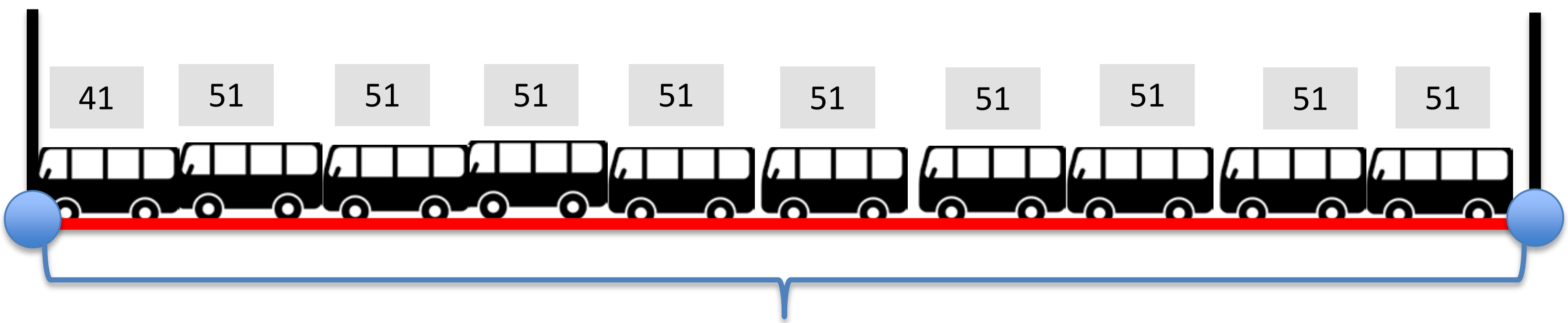


$$Freq = \frac{MaxLoad}{VSize * LoadFactor}$$



MaxLoad = 500

9 meter Bus capacity @ 85% Load Factor =51



Frequency on the Critical Link = 9.8, round up to **10**

6.3 BASIC SERVICE PLANNING CONCEPTS

*Digression: In Low Demand corridors, where a demand-derived frequency would drop below a socially acceptable norm, the frequency would be a **policy decision.***

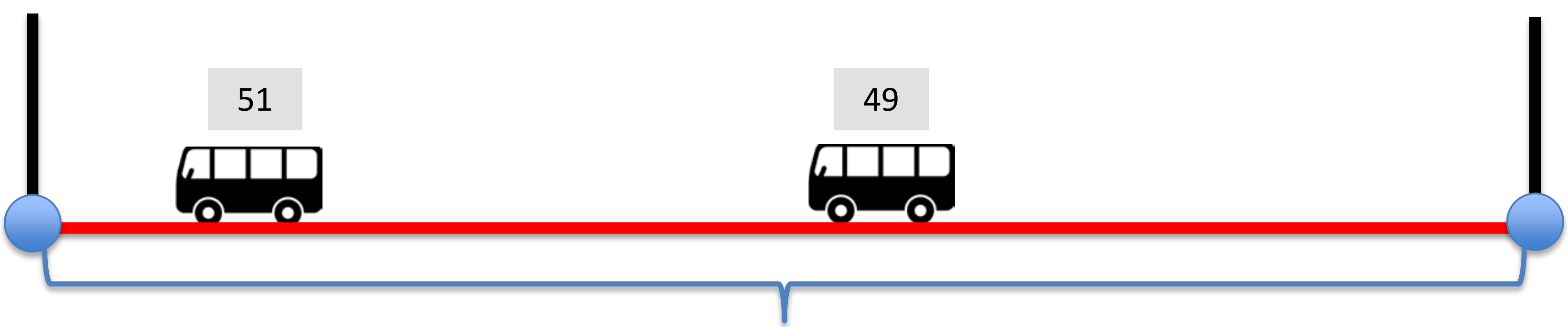
High Demand BRT Corridor

$$Freq = \frac{MaxLoad}{VSize * LoadFactor}$$

Lower demand corridors

$$Freq = \text{Policy Decision}$$

MaxLoad = 100



Frequency on the Critical Link =2 or more, depending on poicy

6.4 OPTIMIZING VEHICLE SIZE AND FLEET SIZE

Frequency vs Vehicle Capacity

Which determines which? Which one to use?

6.4 OPTIMIZING VEHICLE SIZE AND FLEET SIZE

Simple Method:
First iteration, early planning.
Hold frequency constant

$$VSize_{route} = \frac{MaxLoad_{route}}{Freq_{route} * LoadFactor}$$

$$VSize_{route} = \frac{MaxLoad_{route}}{22 * 0.85}$$

Assumptions:

Freq = 22 veh/hr:
Highest frequency attainable in a BRT corridor without introducing significant irregularity. Based on empirical observation.

BRT Demand = Existing Demand + 20%:
Typically correct for early years planning.

First Iteration for Bus Sizing			
Existing Max Load	MaxLoad + 20% w BRT	Optimal Size	Suggested Vehicle Size
3500	4200	191	Split the route
3250	3900	177	Bi-articulated or split route
3000	3600	164	Bi-articulated or split route
2750	3300	150	Bi-articulated or split route
2500	3000	136	Bi-articulated or split route
2250	2700	123	Articulated
2000	2400	109	Articulated
1750	2100	95	Articulated
1500	1800	82	12 meter bus
1250	1500	68	12 meter bus
1000	1200	55	12 meter bus
750	900	41	9 meter bus
500	600	27	9 meter bus
250	300	14	9 meter bus

6.4 OPTIMIZING VEHICLE SIZE AND FLEET SIZE

Complex Method:
Use in detailed planning, more accurate.
Does not assume a base frequency.

Optimal vehicle size is the one where the extra waiting costs of lower frequency (denominator) and the costs of operating the bus that *do not* vary with vehicle size (numerator).

$$VSize_{optimum} * LoadFactor = \sqrt{\frac{BusFixedCost * MaxLoadperCycle_{route}}{Ren_{corridor} * Cost_{wait} * 0.5 * (1 + Irr_{city})}}$$

6.4 OPTIMIZING VEHICLE SIZE AND FLEET SIZE

Once you have determined the optimal Vehicle Size, you may then determine the actual optimal frequency.

This, like most calculations, are iterative.....

After determining vehicle size, determine Fleet size

6.4 OPTIMIZING VEHICLE SIZE AND FLEET SIZE

Simplified Scenario:

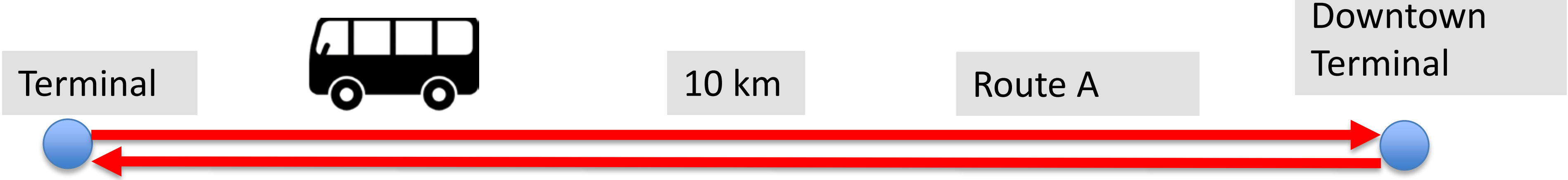
Demand is constant throughout the day

$$Fleet_{route} = \frac{MaxLoad_{route} * TC}{VSize * LoadFactor}$$

Current speed, Route A bus = 10 kph
Planning speed, Route A BRT = 25 kph

$MaxLoad_{\text{Route A}}$ = 510

VSize (9M) * 0.85 = 51



Bus Cycle Time = 125 minutes
BRT Cycle Time = 53 minutes

Current Fleet (9m buses) = (510 pax * (125 min / 60 min)) / 51 pax = 20.83, round up to **21**
BRT Fleet (9m buses) = (510 pax * (53 min / 60 min)) / 51 pax = 8.83, round up to **9**

6.4 OPTIMIZING VEHICLE SIZE AND FLEET SIZE

15 Minute Loads	
Time	15 Minute Loads
6:00 a.m.	15
6:15 a.m.	21
6:30 a.m.	31
6:45 a.m.	51
7:00 a.m.	63
7:15 a.m.	69
7:30 a.m.	67
7:45 a.m.	66
8:00 a.m.	53
8:15 a.m.	45
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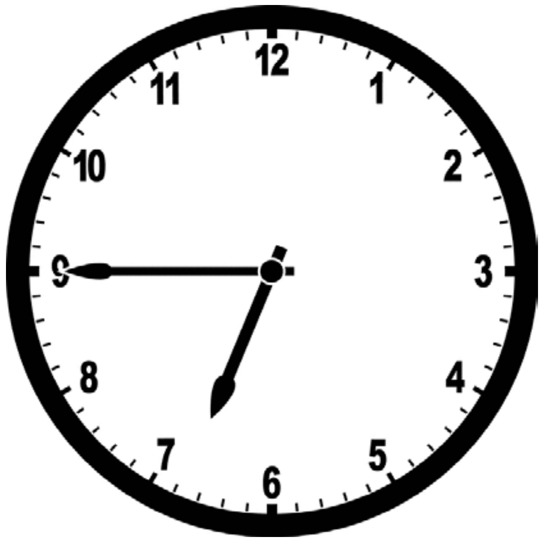


Peaked Demand Scenario:

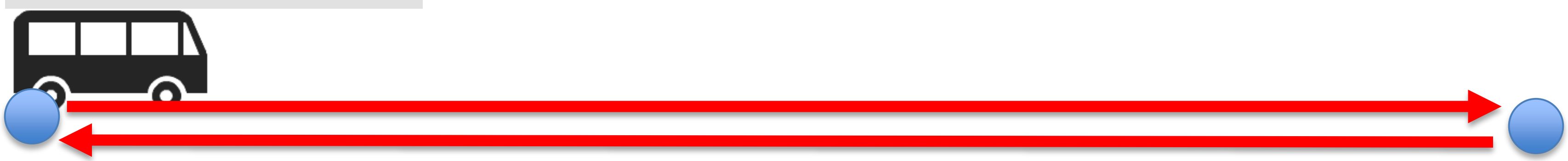
$$Fleet_{route} = \frac{MaxLoadperCycle_{route}}{VSize * LoadFactor}$$

Max Load Per Cycle:

Maximum passenger demand that will cross the critical link during the course of 1 bus' cycle.

Example Cycle time = 1 hour.

6:45 bus picks up all waiting passengers



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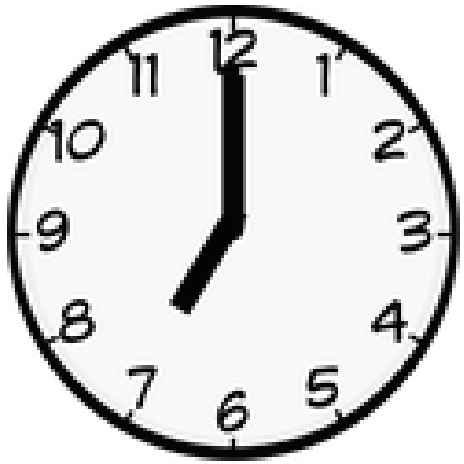

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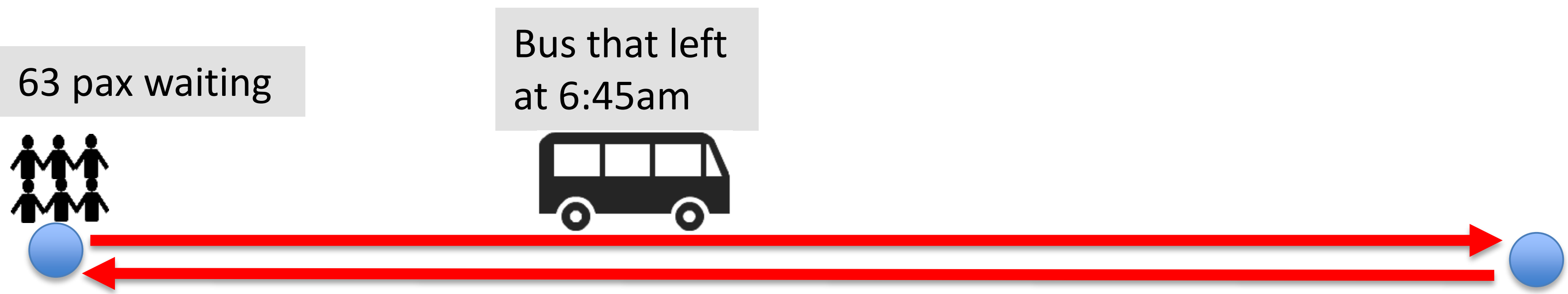
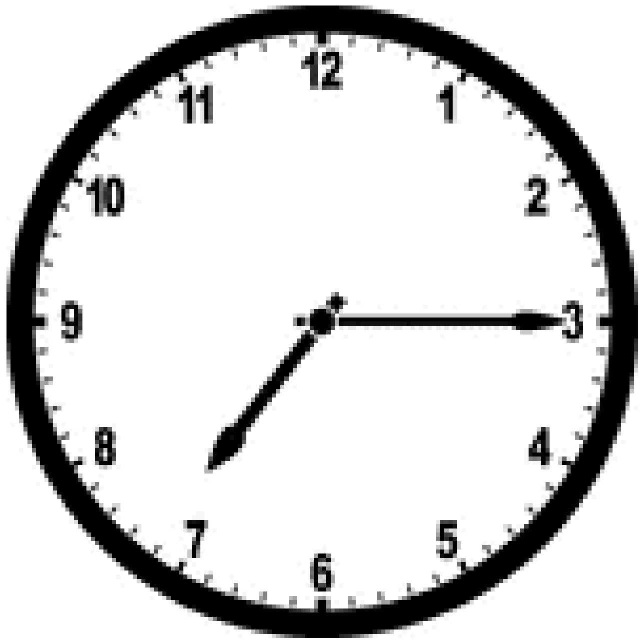


6.4 OPTIMIZING VEHICLE SIZE AND FLEET SIZE



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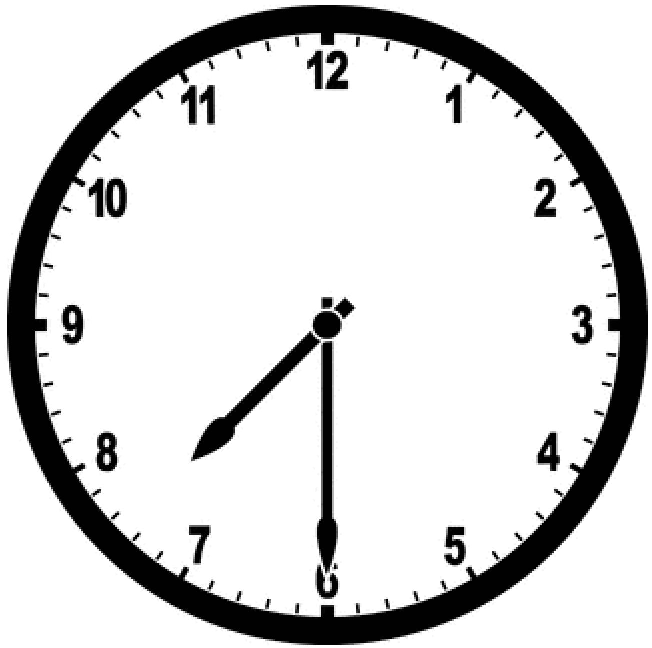
7:45 a.m.	66
8:00 a.m.	53
8:15 a.m.	45
8:30 a.m.	34
8:45 a.m.	32

63 + 69 = 132 pax waiting

Bus that left at 6:45am

6.4 OPTIMIZING VEHICLE SIZE AND FLEET SIZE



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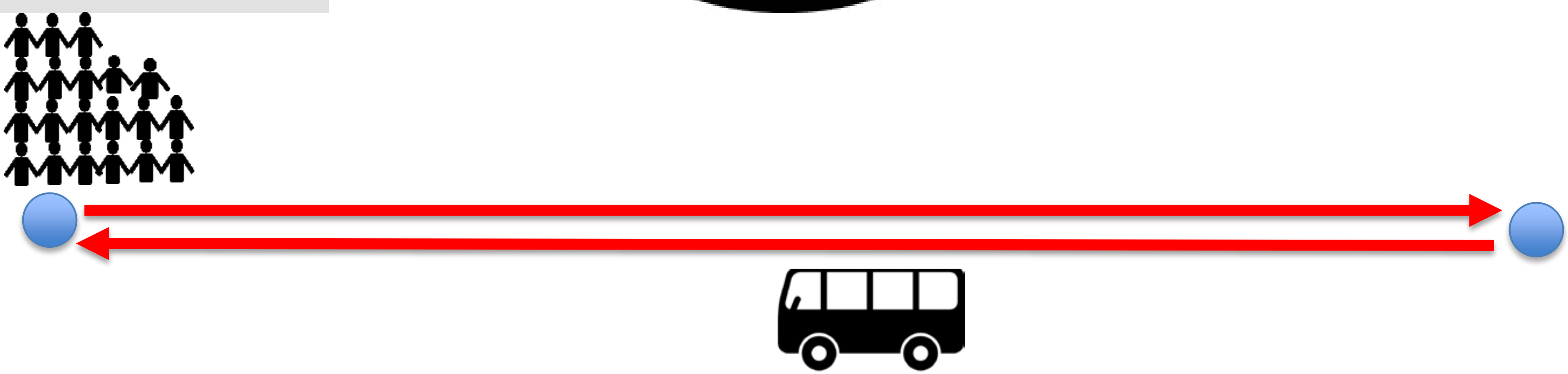
7:30 a.m.	67
7:45 a.m.	66
8:00 a.m.	53
8:15 a.m.	45
8:30 a.m.	34
8:45 a.m.	32

132 + 67 =
199 pax waiting

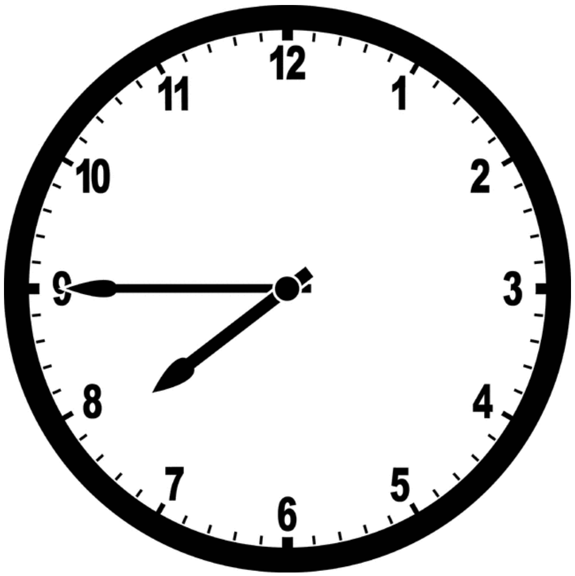


Bus that left at 6:45am now returning

6.4 OPTIMIZING VEHICLE SIZE AND FLEET SIZE

Cycle is over.

Max Load per Cycle = **265**



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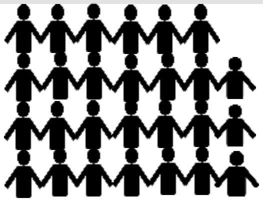
8:00 a.m.	53
8:15 a.m.	45
8:30 a.m.	34
8:45 a.m.	32

199 + 66 =
265 pax waiting



Bus that left at 6:45am now back to pick up passengers

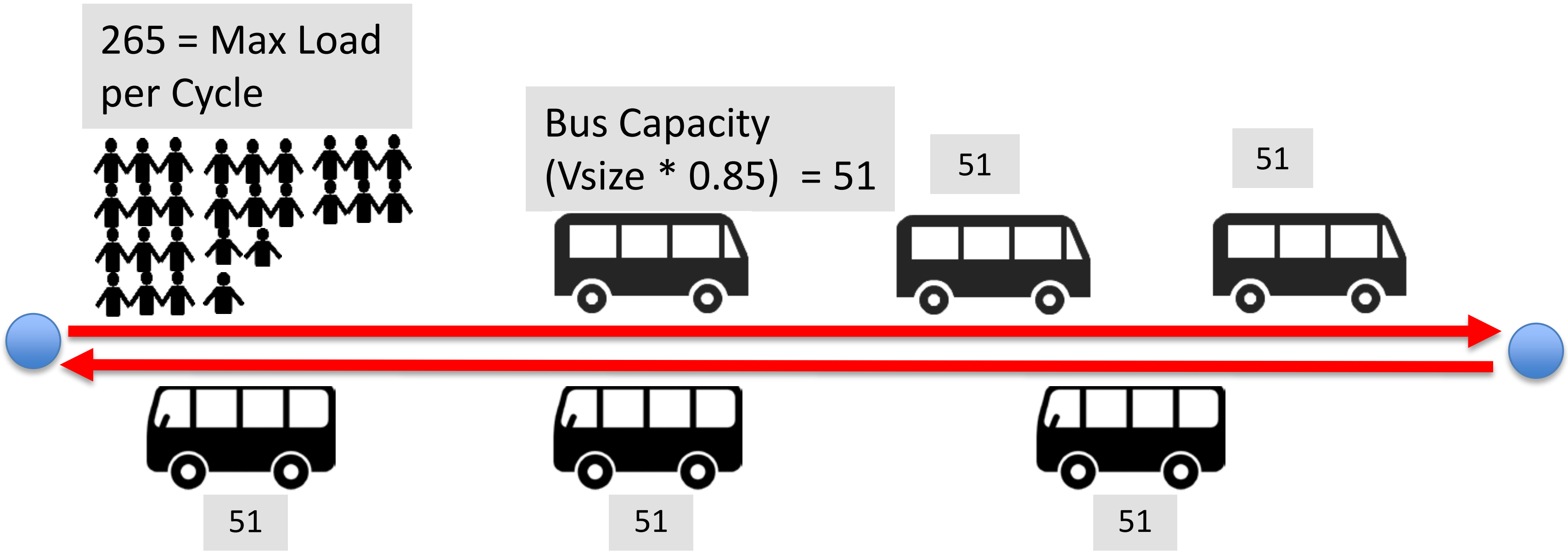
6.4 OPTIMIZING VEHICLE SIZE AND FLEET SIZE

*Now we can calculate the **fleet**! Assume 9m buses. We can re-optimize bus size using previous methods*

Eq. 6.20

$$Fleet_{route} = \frac{MaxLoadperCycle_{route}}{VSize * LoadFactor}$$

Fleet = 265 pax / 51 pax = 5.19, so round up to **6**



6.5 Determining Which Routes to Include Inside BRT Infrastructure

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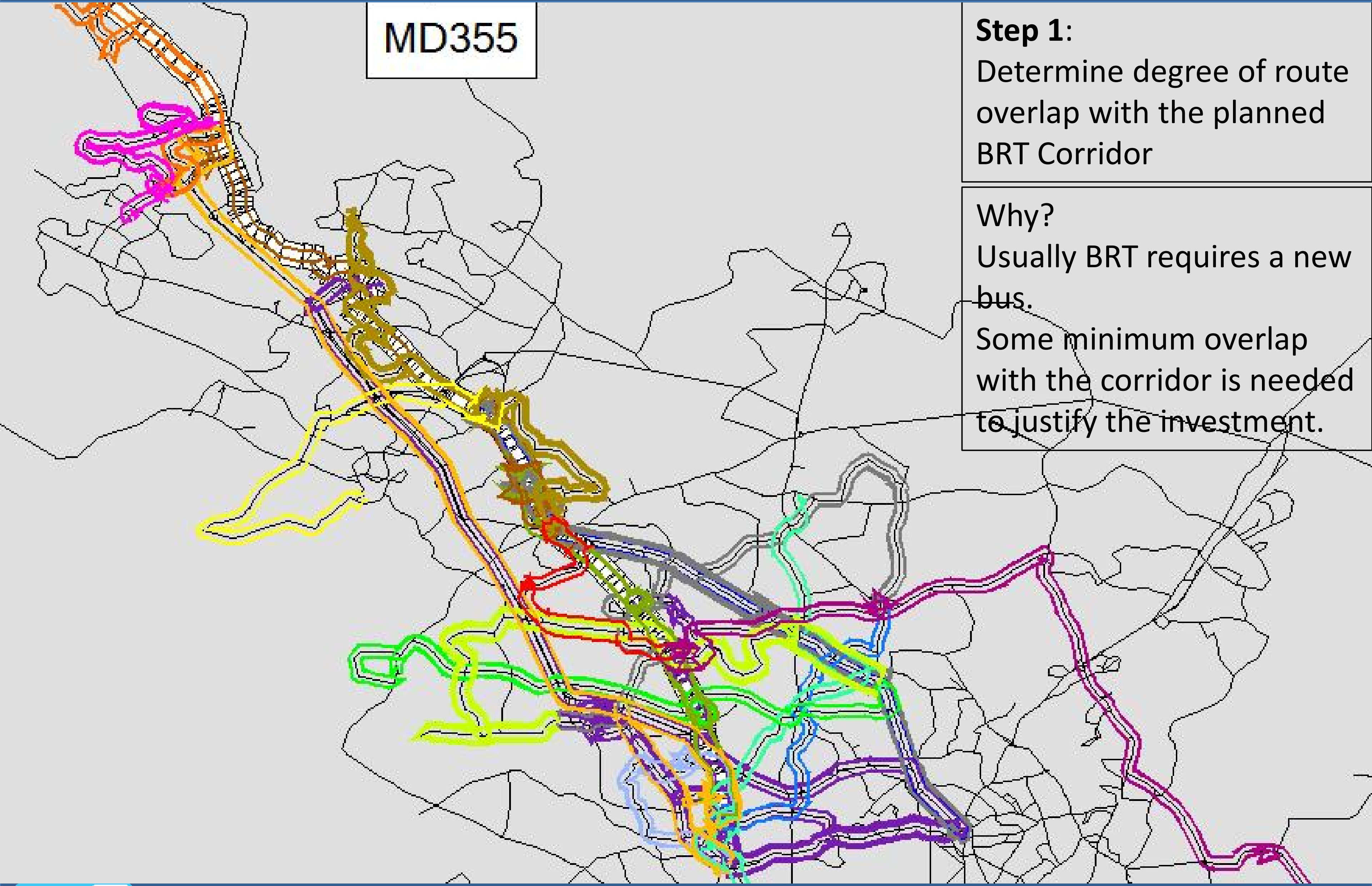


Step 1:
Determine degree of route overlap with the planned BRT Corridor

Why?
Usually BRT requires a new bus.
Some minimum overlap with the corridor is needed to justify the investment.

6.5 Determining Which Routes to Include Inside BRT Infrastructure

line	# of daily trips	fleet	ALL LINE		IN CORRIDOR	
			Total Pax	Vehicle miles	route extension	passenger time
026R	89	8	3,328	1,382	4%	5%
030R	59	4	640	405	25%	36%
033R	32	3	353	224	5%	9%
034R	93	7	2,721	819	23%	27%
037R	27	3	224	244	5%	6%
038R	69	5	1,385	923	8%	15%
046R	126	8	4,023	1,200	100%	100%
055R	134	11	7,579	2,140	89%	99%
059R	98	7	3,859	1,247	35%	39%
067R	12	1	141	120	12%	12%
070R	55	7	721	1,070	12%	25%
075R	56	2	392	518	11%	17%
081R	31	2	217	184	22%	37%
083R	86	4	673	641	7%	4%
0C8W	64	6	2,200	1,147	3%	1%
0J1W	30	3	341	136	8%	13%
0J2W	140	9	4,829	1,761	20%	35%
0J3W	25	4	711	277	17%	33%
0J5W	20	2	303	226	22%	24%
0J7W	11	2	110	172	17%	32%
0J9W	22	3	357	363	19%	26%
0Q1W	9	-	400	120	21%	13%
0Q2W	34	-	1,666	445	21%	9%
0Q5W	5	-	303	49	30%	25%
0Q6W	75	8	2,416	812	37%	31%

Step 1:
Determine which existing bus routes overlap with the planned BRT Corridor

Metrics:

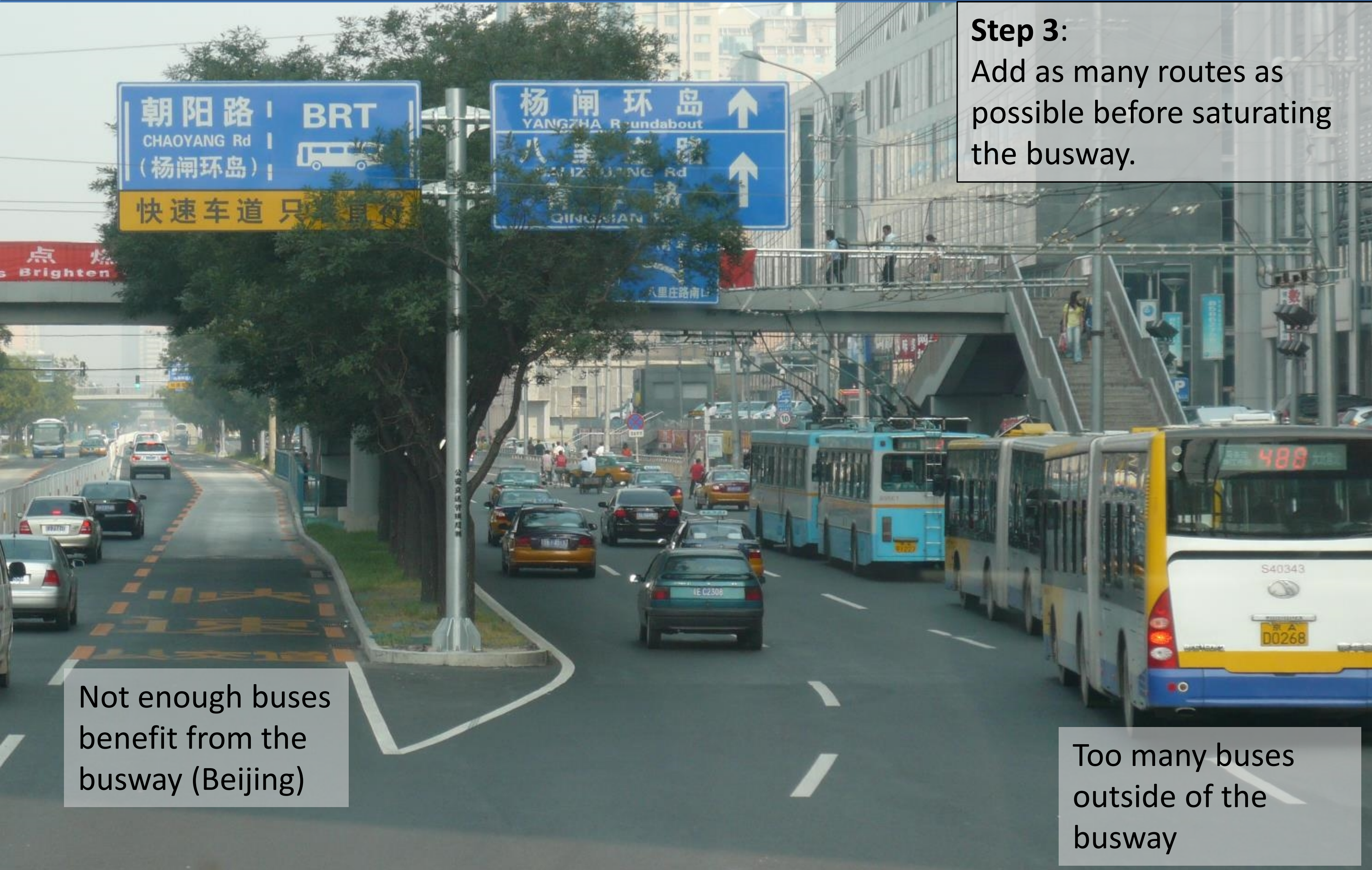
- % of BRT Corridor used
- % of each route on BRT Corridor
- % of total trip time on Corridor

Usually a 25% cut-off is used, but there is no hard rule

6.5 Determining Which Routes to Include Inside BRT Infrastructure

Step 2:
Consider administrative authority. Only buses controlled by the BRT Authority should be allowed access

6.5 Determining Which Routes to Include Inside BRT Infrastructure

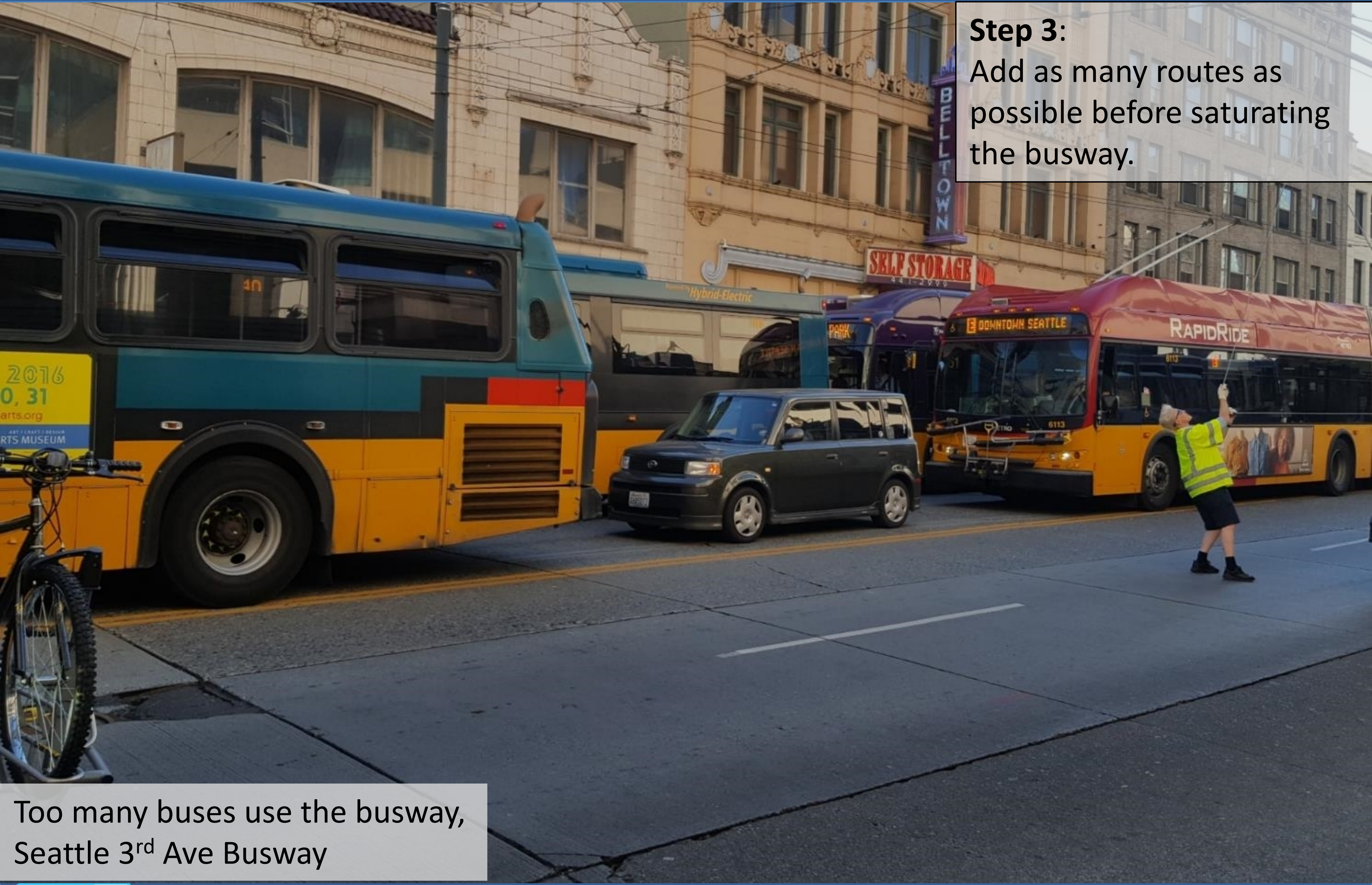


Step 3:
Add as many routes as possible before saturating the busway.

Not enough buses benefit from the busway (Beijing)

Too many buses outside of the busway

6.5 Determining Which Routes to Include Inside BRT Infrastructure

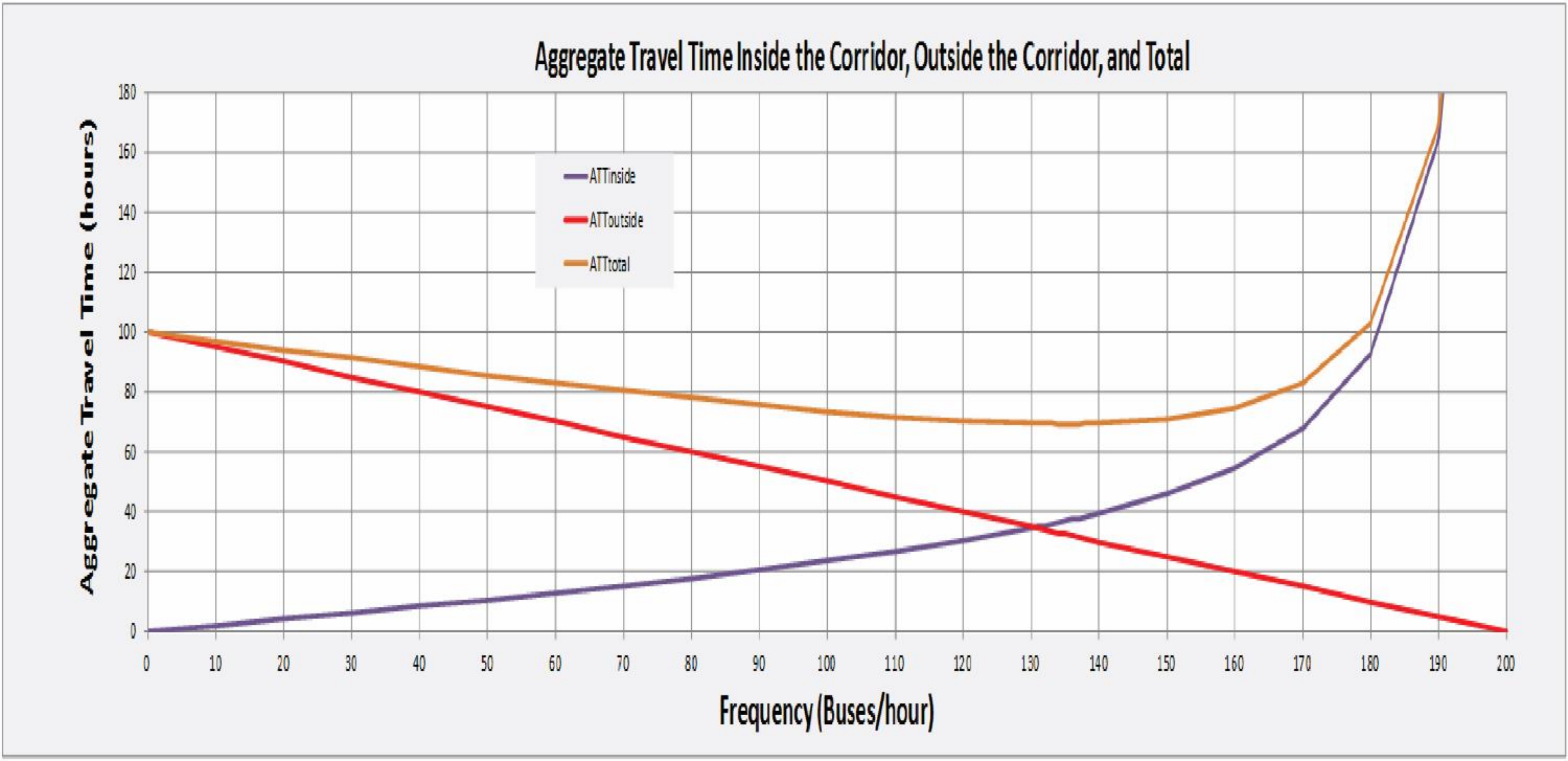


Step 3:
Add as many routes as possible before saturating the busway.

Too many buses use the busway, Seattle 3rd Ave Busway

6.5 Determining Which Routes to Include Inside BRT Infrastructure

The total benefits of adding buses to a busway decline when the busway begins to saturate



6.5 Determining Which Routes to Include Inside BRT Infrastructure

Busway saturation occurs at the stations.

Station saturation occurs when buses are occupying a bus stop for 40% of the time, or 1440 seconds in an hour.

Saturation is calculated as follows:

$$x = T_d * F_{\text{inside}}$$

where

x = saturation level of the bus stop

T_d = Total dwell time per bus (passengers boarding and alighting, bus opening and closing doors)

F_{inside} = Frequency inside the busway

6.5 Determining Which Routes to Include Inside BRT Infrastructure

Rank the routes to decide which to bring in.
At the peak demand station,

Moves the most passengers [Pax(i)]
Relative to the dwell time that it adds [Td(i)] to that station

$$\text{Priority}(i) = \frac{\text{Pax}(i)}{T_d(i)}$$

Where:

- $\text{Priority}(i)$: Priority index of route "i"; Passengers per second of dwell time on route "i" at the bottleneck station;
- $\text{Pax}(i)$: Average occupancy of each bus on route "i" as the bus passes the station;
- $T_d(i)$: Total dwell time in seconds of each bus on route "i".

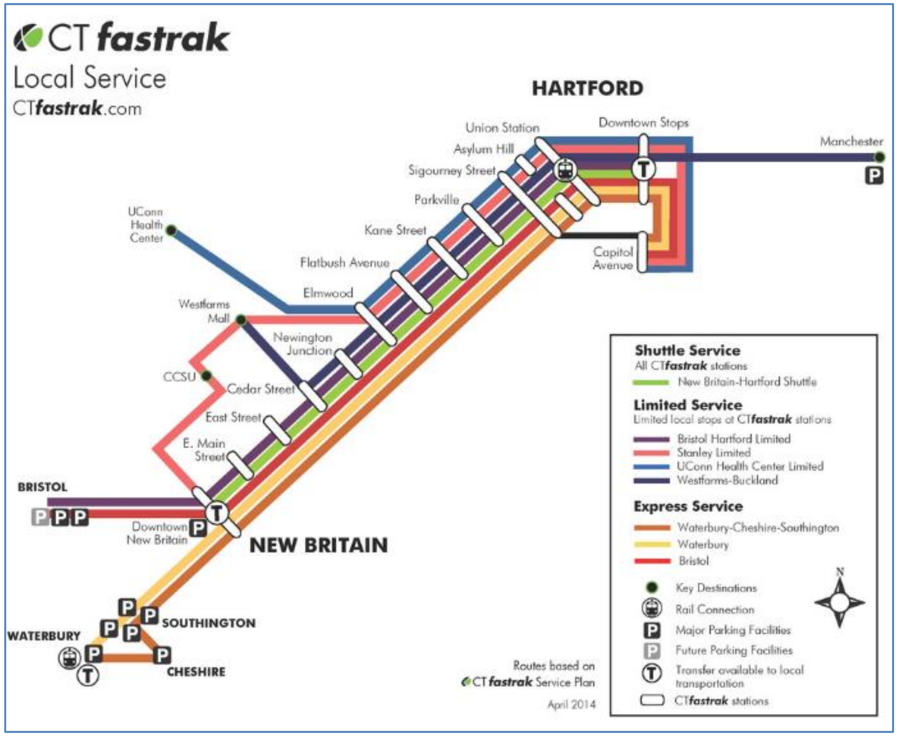
6.5 Determining Which Routes to Include Inside BRT Infrastructure

Rank the routes by "Priority"

Keep adding routes until the busway saturates

Route Values					Accumulated values on station after route inclusion		
Route	Frequency (surveyed or planned)	Customers of route i passing through station	Bus station use required by route	Priority index (passengers in the system per second of station use)	Frequency inside the busway	Customers inside the busway	Station saturation
i	F_i	Load_i = O_i * F_i	x_i = T_d * F_i / 3600	priority_i = Load_i / T_d	Sum(F_i)	Load_inside = Sum(O_i * F_i)	x_station = Sum(x_i)
unit-->	vehicle /hour	pax/hour		pax/second	vehicle /hour	pax/hour	
B	20	1000	6%	5.00	20	1000	0.056
F	25	500	3%	5.00	45	1500	0.083
K	10	480	3%	4.80	55	1980	0.111
H	23	1265	8%	4.58	78	3245	0.188
D	2	1804	13%	3.90	100	5049	0.316
M	4	232	2%	3.87	104	5281	0.333
G	8	320	4%	2.50	112	5601	0.368
J	15	1230	15%	2.28	127	6831	0.518
A	15	900	13%	2.00	142	7731	0.643
I	8	560	9%	1.79	150	8291	0.73
E	5	450	8%	1.50	155	8741	0.813
L	6	354	9%	1.16	161	9095	0.898
C	18	720	20%	1.00	179	9815	1.098

6.6 Direct Services, Trunk-and-Feeder Services, or Hybrids



Direct Services:
Hartford-New Britain BRT

Trunk and Feeder Services:
Lima BRT

6.6 Direct Services, Trunk-and-Feeder Services, or Hybrids

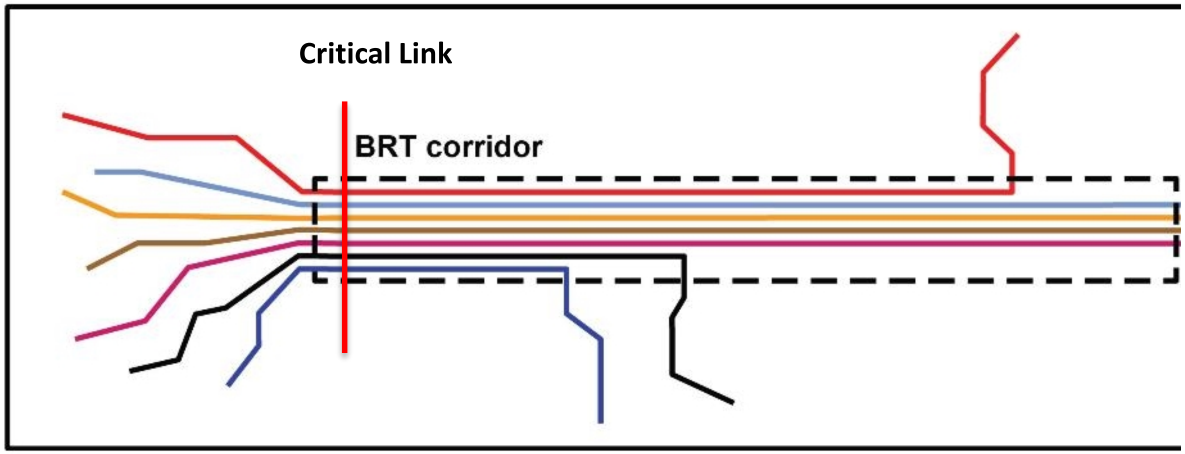
First question:
Can local off-corridor streets handle BRT buses?

Sometimes very narrow streets or steep hills off-corridor require splitting routes

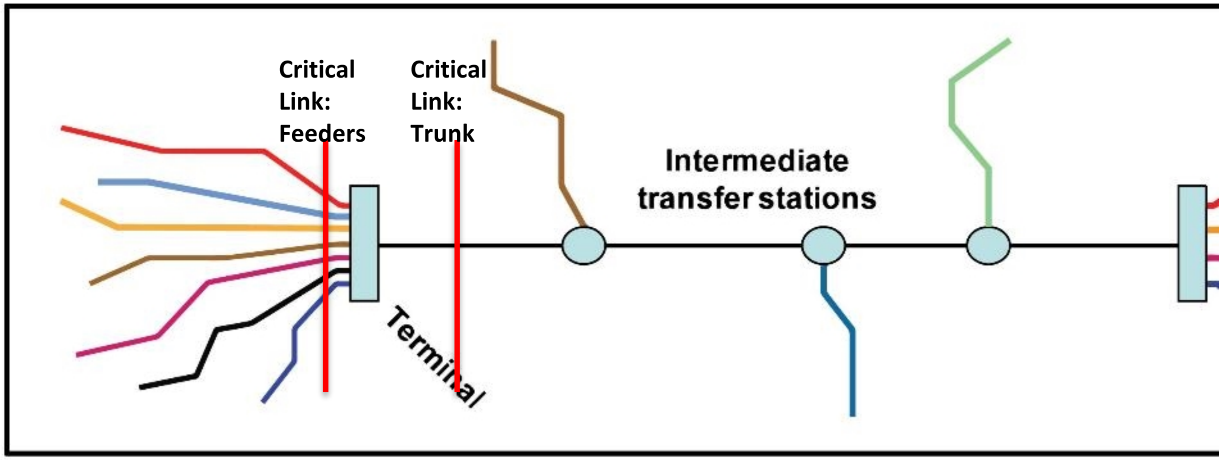
6.6 Direct Services, Trunk-and-Feeder Services, or Hybrids

6.6.1 Fleet Requirements
6.6.2 Vehicle Size
6.6.3 Transfer and Terminal Delay
6.6.4 Station and Platform saturation

6.6.1 Direct Services, Trunk-and-Feeder Services, or Hybrids: **Fleet Requirements**



Direct services



Trunk-and-feeder services

Fleet size for each route is determined based on the link with the **highest demand**.

Determining fleet size for Direct Service routes vs Trunk-and-Feeder routes requires determining **critical link** for each route.

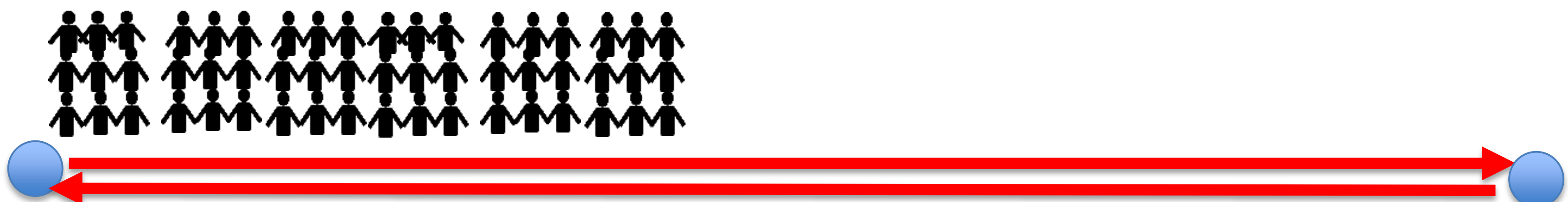
6.6.1 Direct Services, Trunk-and-Feeder Services, or Hybrids: **Fleet Requirements**

Direct Services:
Assume 2 hour cycle time: 1 hour for off-corridor section and 1 hour for on-corridor section.

15 Minute Loads	
Time	15 Minute Loads
6:00 a.m.	15
6:15 a.m.	21
6:30 a.m.	31
6:45 a.m.	51
7:00 a.m.	63
7:15 a.m.	69
7:30 a.m.	67
7:45 a.m.	66
8:00 a.m.	53
8:15 a.m.	45
8:30 a.m.	34
8:45 a.m.	32
9:00 a.m.	21

$MaxLoadperCycle_{Direct} = 448$

Total Fleet$_{\mathbf{Direct}}$ = 448/51 = **8.78**, round up to **9**



Direct Services require only 9 * 51 pax buses to carry the 448 pax that would accumulate in the 2 hour cycle time.

15 Minute Loads	
Time	15 Minute Loads
6:00 a.m.	15
6:15 a.m.	21
6:30 a.m.	31
6:45 a.m.	51
7:00 a.m.	63
7:15 a.m.	69
7:30 a.m.	67
7:45 a.m.	66
8:00 a.m.	53
8:15 a.m.	45
8:30 a.m.	34
8:45 a.m.	32

$MaxLoadperCycle_{Feeder} = MaxLoadperCycle_{Trunk} = 265$

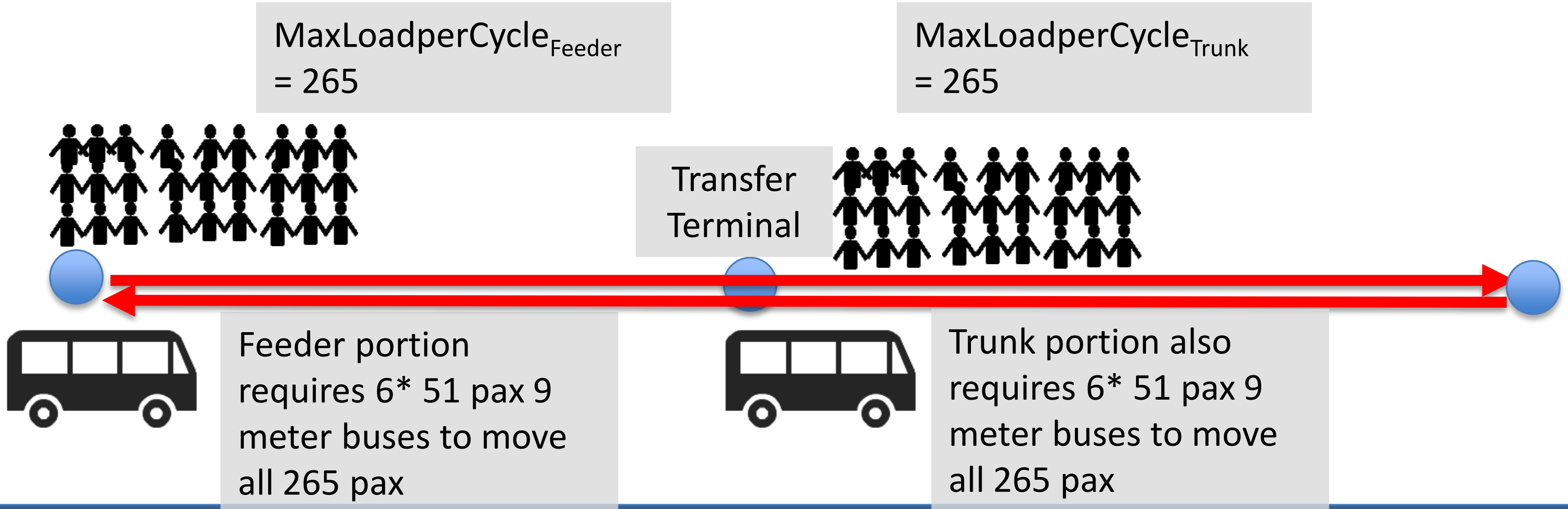
$Fleet_{Feeder} = Fleet_{Trunk} = 265/51 = 5.19$, round up to 6.

Total Fleet $_{\textbf{trunk-and-feeder}}$ = $Fleet_{Feeder} + Fleet_{Trunk} = 6 + 6 =$ **12**

Trunk-and-Feeder:

Assume 1 hour cycle time for feeder routes & 1 hour cycle time for trunk routes.

Assume demand on critical link for feeders entering transfer terminal = demand on critical link for trunk exiting transfer terminal.



6.6.1 Direct Services, Trunk-and-Feeder Services, or Hybrids: **Fleet Requirements**

Direct services typically require less fleet.

In plain English, this is because trunk-and-feeder services generally **split the demand** at the critical link of one or both routes. The result is that this peak demand needs to be **served twice**: once by trunk buses and once by feeder buses.

Direct service routes, on the other hand, carry the same demand **all the way through**. While their routes are longer and more fleet is needed per route, **the complete demand** is served by one route.

6.6.2 Direct Services, Trunk-and-Feeder Services, or Hybrids: **Vehicle Size**

But wait! The trunk can use bigger buses, and bigger buses are more *efficient*!

How big will this effect be?

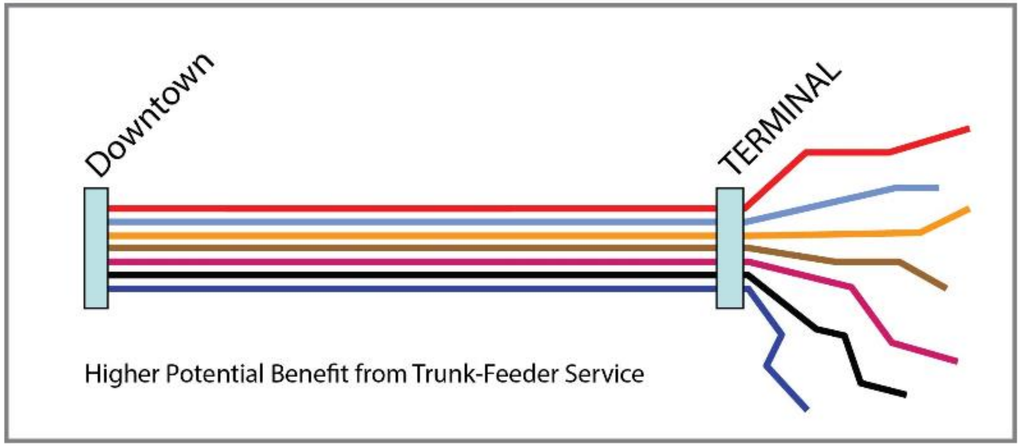
Efficient economies of scale on the trunk, less efficient on the feeder portion of the route .

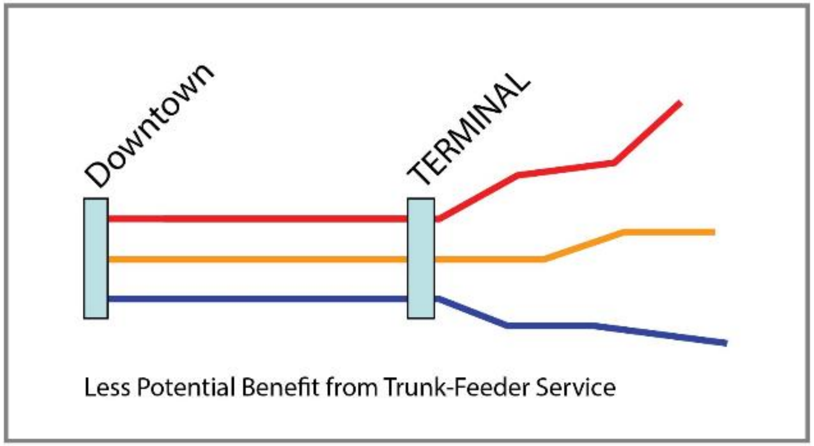
Therefore,

The longer the Trunk Route relative to the total route, the greater the vehicle size benefit of trunk-and-feeder

The greater the number of feeder Routes, the more benefit from larger buses on the trunk

Range of benefit: 5% to 40%, with 10% the norm.





6.6.2 Direct Services, Trunk-and-Feeder Services, or Hybrids: **Vehicle Size**

Larger vehicles are more efficient

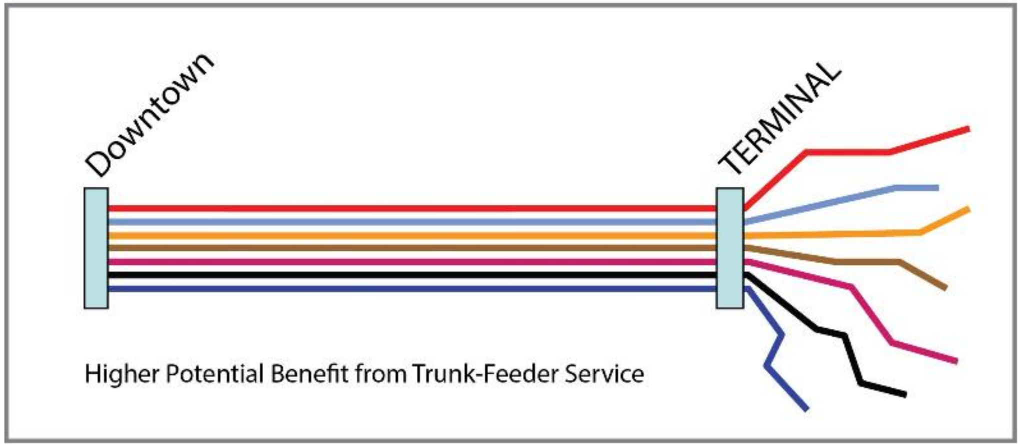
Larger optimal vehicle size on the trunk

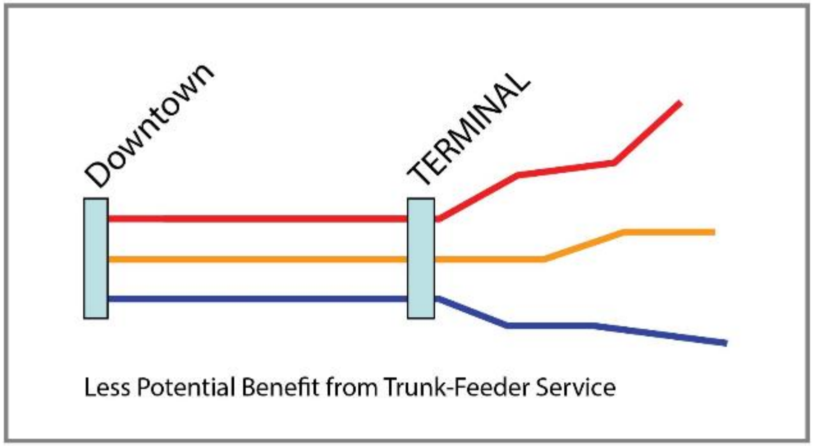
Smaller optimal vehicle size on the feeder

Therefore,

>Trunk Route/Total Route, > benefit

>#Feeder Routes, > benefit

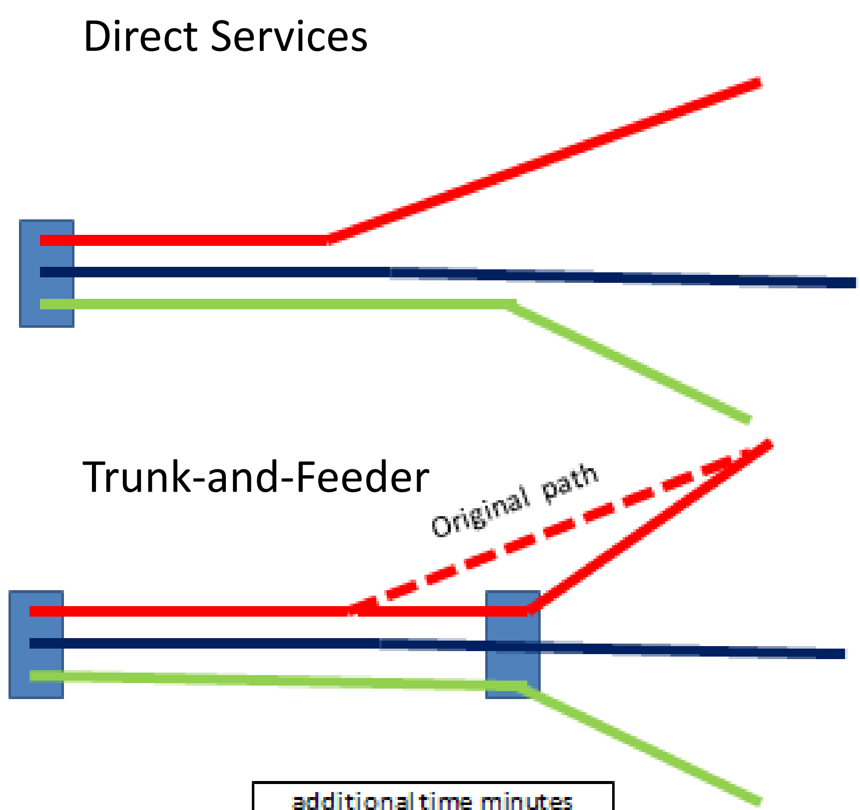




6.6.3 Direct Services, Trunk-and-Feeder Services, or Hybrids: **Transfer and Terminal Delay**

Indirectness of route:
Sometimes feeder routes must be rerouted in order to have access to a transfer terminal that benefits all routes.

This causes indirectness of route to passengers on that feeder route.

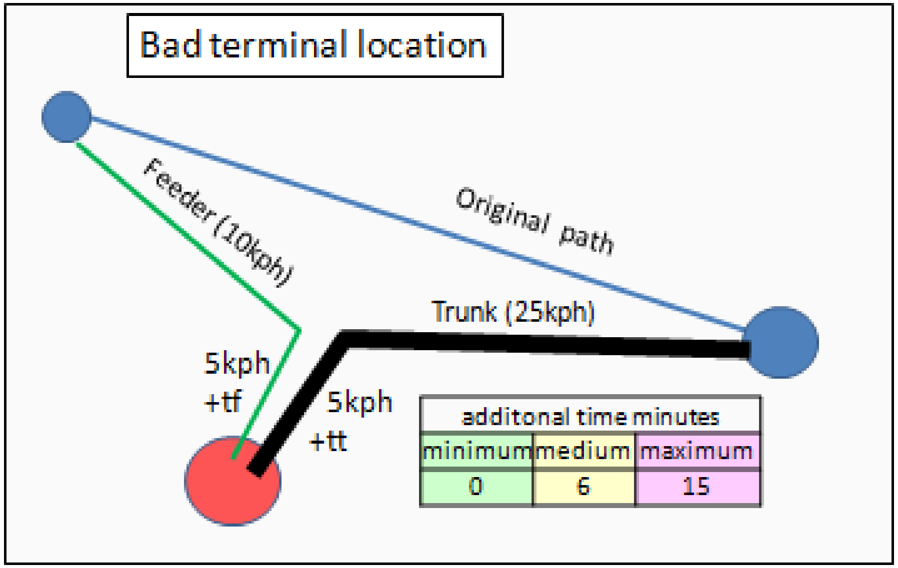


additional time minutes		
minimum	medium	maximum
0	4	10

Other times, transfer must be built off the trunk corridor completely due to difficult land acquisition issues.

All services must be rerouted, adding distance.

TransMilenio (Bogota) terminal immediately adjacent to the Trunk



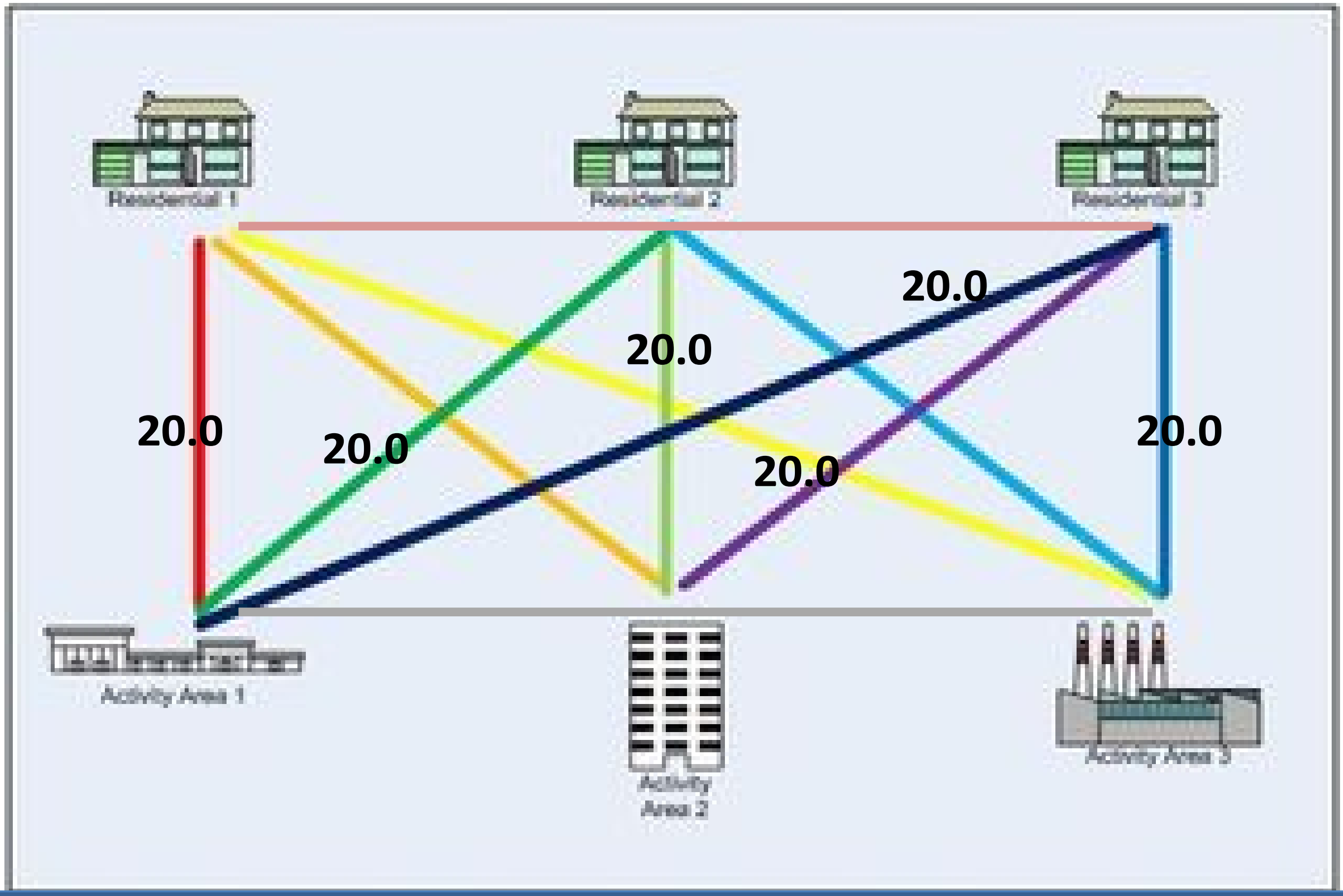
additonal time minutes		
minimum	medium	maximum
0	6	15

Leon, Mexico terminal, 600 meters from the trunk corridor

Digression: Human Transit's defense of transfers

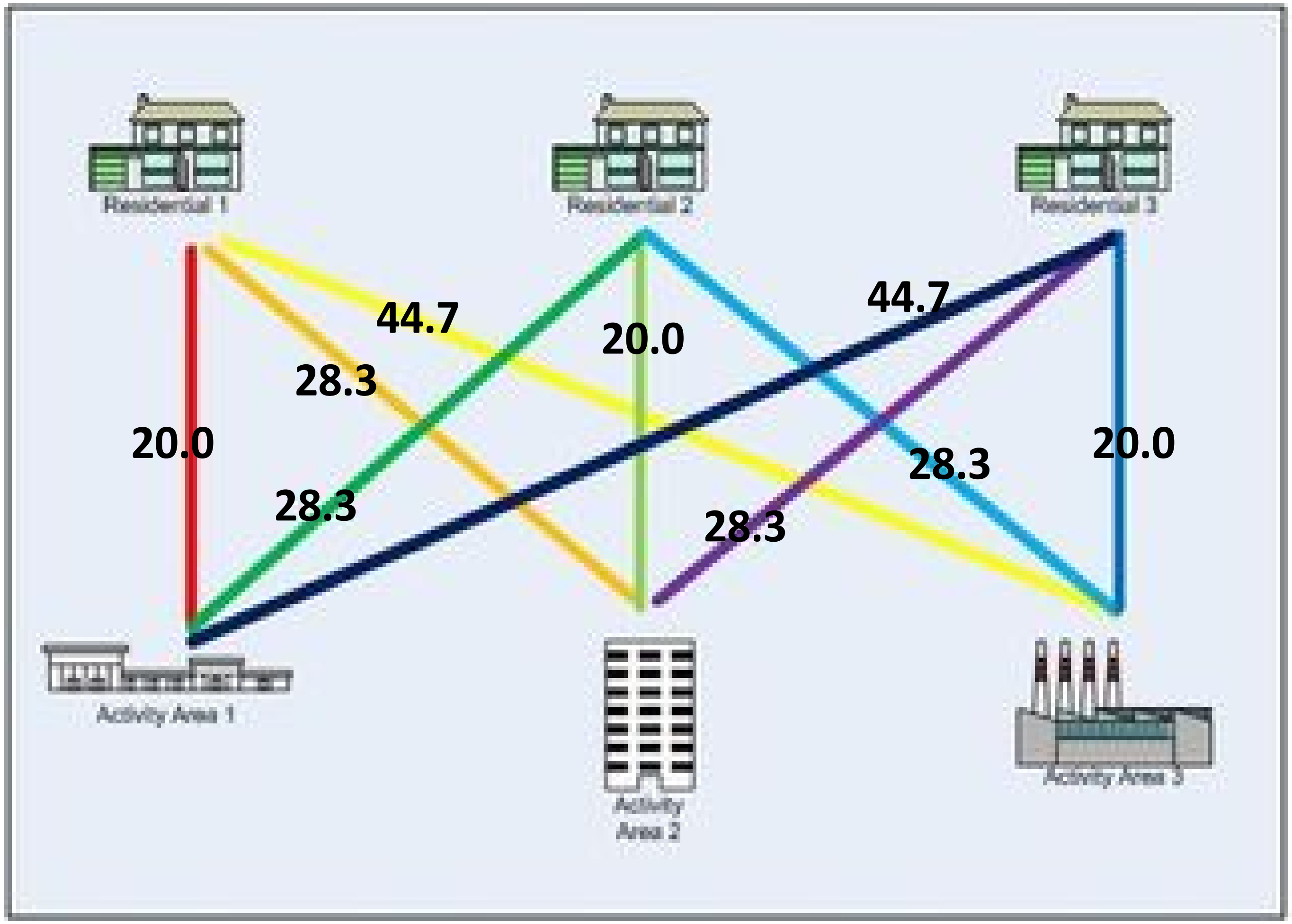
1. All trips take 20 minutes.

This assumption **incorrectly erases** indirectness of route problem



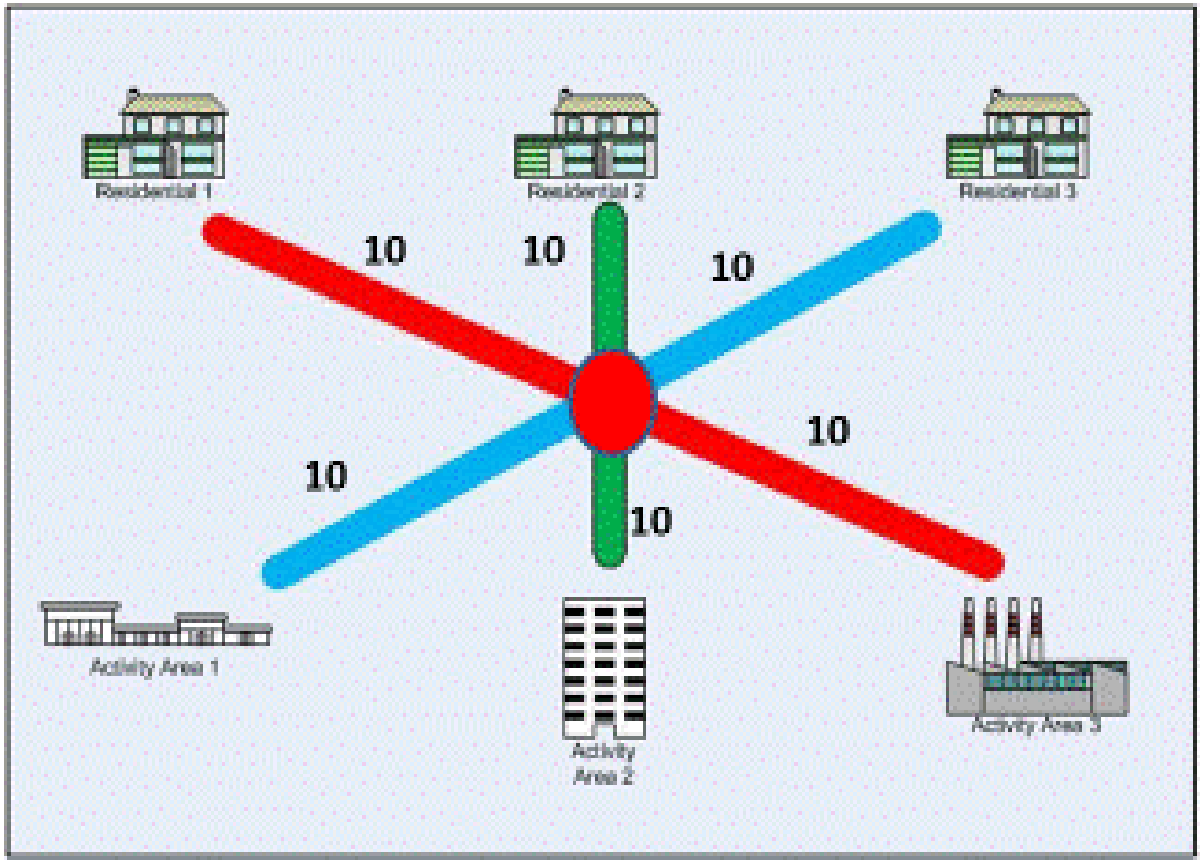
Digression: Human Transit's defense of transfers

Corrected for Pythagorean theorem.



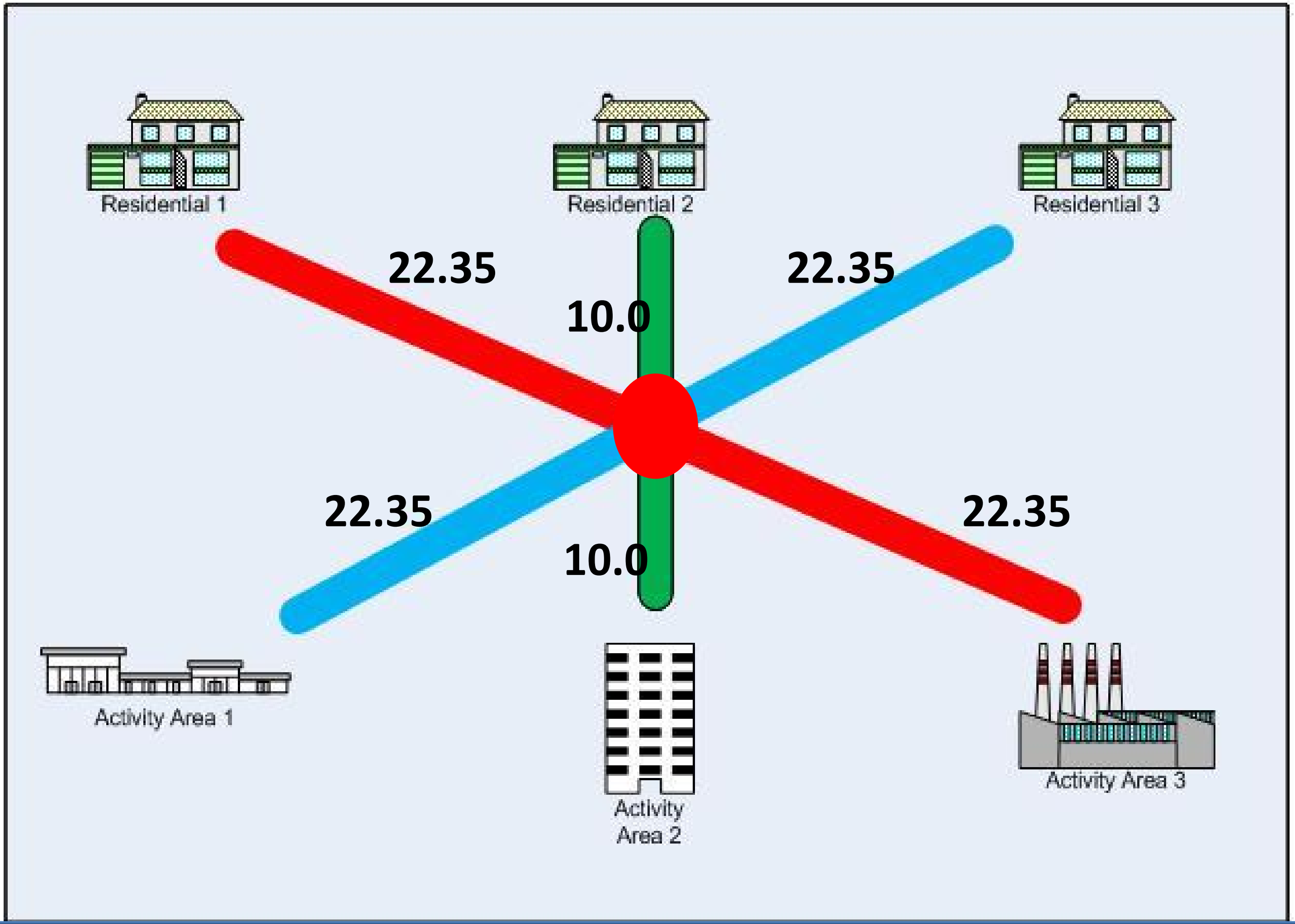
Digression: Human Transit's defense of transfers

2. Combine 9 direct routes into 3 routes with a central transfer terminal in order to triple frequency.



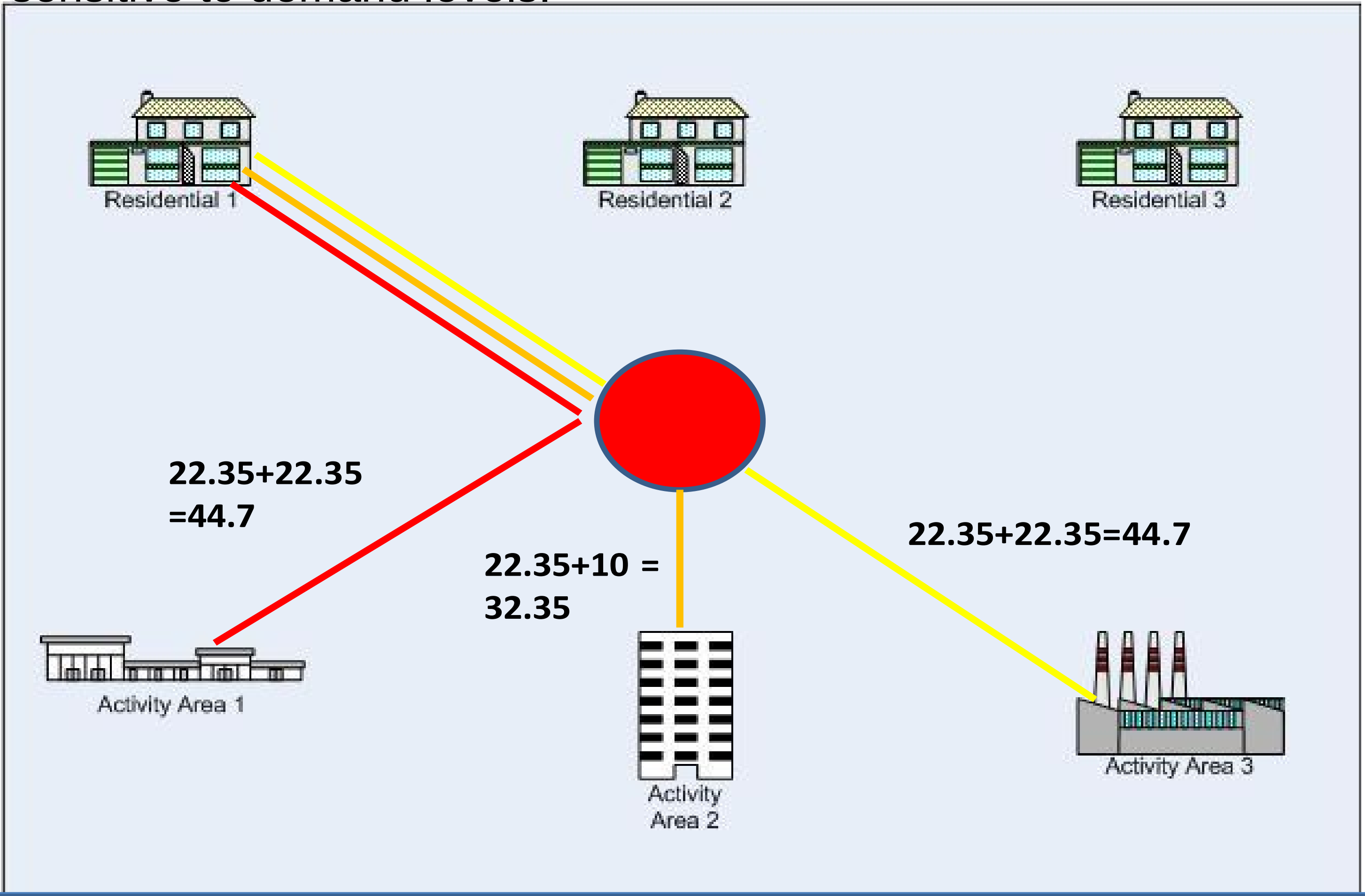
Digression: Human Transit's defense of transfers

Corrected for Pythagorean theorem. Most original travel times are longer due to **indirectness of route**.



Digression: Human Transit's defense of transfers

This indirectness of route (and loss of service coverage) usually overwhelms the benefits of increased frequency.
Results are sensitive to demand levels.



6.6.3 Direct Services, Trunk-and-Feeder Services, or Hybrids: **Transfer and Terminal Delay**

- Cost of constructing the terminal
- Passenger waiting time inside the terminal
- Passenger walking time inside terminal

6.6.4 Direct Services, Trunk-and-Feeder Services, or Hybrids: **Station and Platform saturation**

Benefit of trunk-and-feeder:

Increased trunk frequency reduces # of passengers waiting on each platform and moves them to a transfer terminal

Useful when not possible to get right of way for sufficiently wide trunk stations. However, requires large transfer stations.

6.7 Deciding on Stop Elimination and Express Services

When you split an existing route into a local and an express route, the following happens:

- Demand for each route is split between the two services
- The frequency of service for all passengers will drop.
- The regularity of service will change
- The travel time for the new express customers will drop based on the removal of fixed dwell time (from stops removed)

6.7 Deciding on Stop Elimination and Express Services

Benefit of adding limited stop service =

Value of passenger time savings + Value of operating cost savings

$$T_0 * \sum_{k=skipped\ station} Load_{limited-stop-at-k} * Cost_{travel} + Freq_{limited-stop-at-k} * Cost_{bus}$$

Fixed Dwell Time per bus

Total passengers on board the limited service buses at the stop before the one(s) skipped

Passenger value of time (about 1/3 per capita hourly wage)

Frequency of the limited service

Hourly operating cost of the bus

6.7 Deciding on Stop Elimination and Express Services

Cost of adding a limited stop service= the extra delay (passengers are waiting for 2 services with lower frequency) less any mitigation of the service irregularity (due to more optimal frequency)

$$ExpressCost = WaitCost_{express} + WaitCost_{local} - WaitCost_{originalservice}$$

Where Waiting Cost (service type) =

$$Ren_{Express} * Cost_{wait} * 0.5 * \left(1 + \left(\frac{Freq_{express}}{Freq_{optimum}}\right)^2\right) * LoadFactor * VSize$$

$$Ren_{Local} * Cost_{wait} * 0.5 * \left(1 + \left(\frac{Freq_{local}}{Freq_{optimum}}\right)^2\right) * LoadFactor * VSize$$

$$Ren_{Original} * Cost_{wait} * 0.5 * \left(1 + \left(\frac{Freq_{Original}}{Freq_{optimum}}\right)^2\right) * LoadFactor * VSize$$

6.7 Deciding on Stop Elimination and Express Services

Where Waiting Cost (service type) =

$$Ren_{Express} * Cost_{wait} * 0.5 * \left(1 + \left(\frac{Freq_{express}}{Freq_{optimum}}\right)^2\right) * LoadFactor * VSize$$

Everything except the Frequency of the service and its relationship to the optimum frequency is constant.

6.7 Deciding on Stop Elimination and Express Services

- The utility of adding limited services increases with frequency. Above 31 buses per hour, splitting the route into an express and local *always* makes sense, due to growing irregularity and bus bunching.
- The benefits drop as frequency drops. On routes with frequency below 10 it *rarely* makes sense to add an express.

6.7 Deciding on Stop Elimination and Express Services

What Stopping Pattern?
Service Approaches for a Typology of Origin-Destination Patterns

- Type I: Even demand between all OD pairs
- Type II: Demand clustered at the beginning and end of a route (A BRT transfer terminal and downtown)
- Type III: Demand concentrated at a few popular locations
- Type IV: Constantly declining (increasing) demand (from downtown outward)
- Type V: Extremely high demand

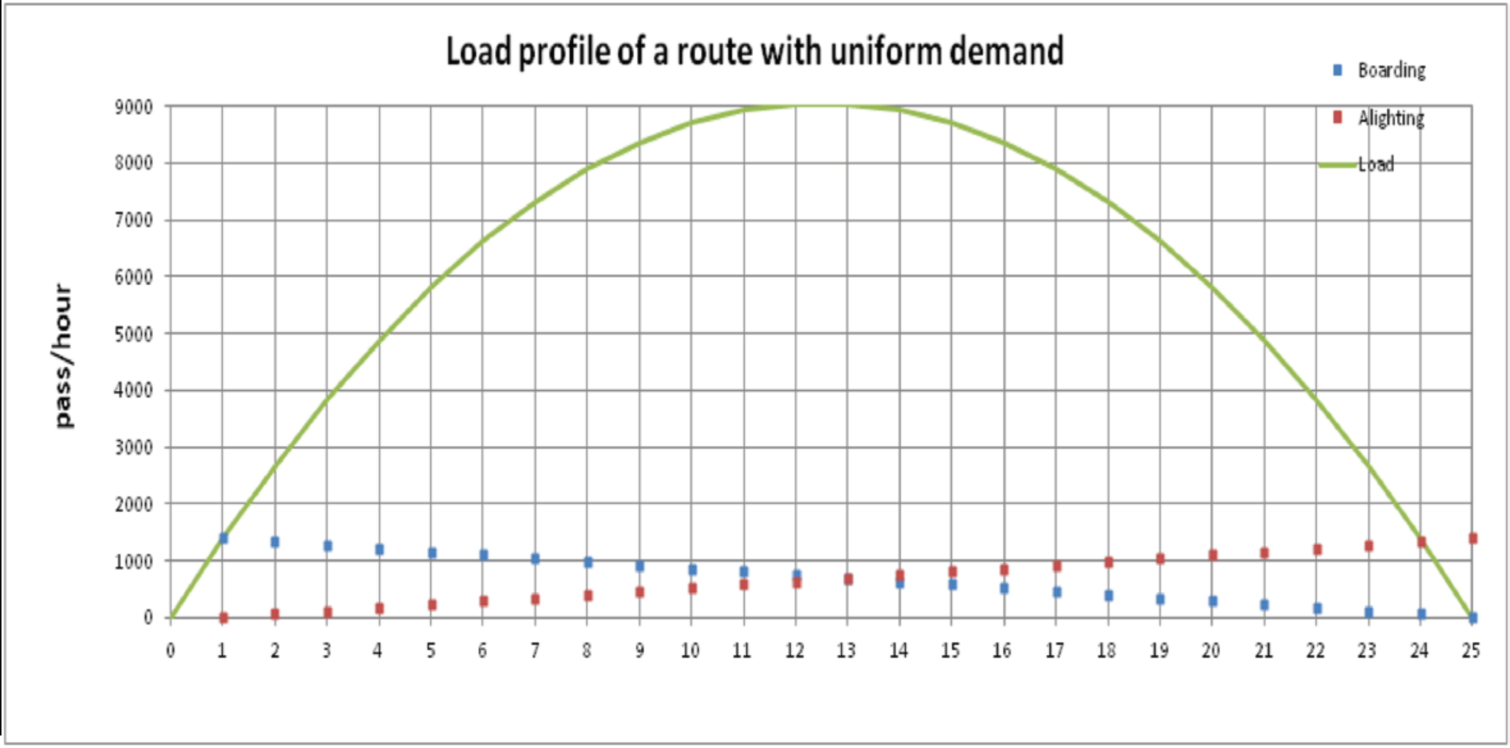
Type I: Even demand between all OD pairs

Zone/Stop	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	Boardings
1	0	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	1392
2		0	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	1334
3			0	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	1276
4				0	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	1218
5					0	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	1160
6						0	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	1102
7							0	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	1044
8								0	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	986
9									0	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	928
10										0	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	870
11											0	58	58	58	58	58	58	58	58	58	58	58	58	58	58	812
12												0	58	58	58	58	58	58	58	58	58	58	58	58	58	754
13													0	58	58	58	58	58	58	58	58	58	58	58	58	696
14														0	58	58	58	58	58	58	58	58	58	58	58	638
15															0	58	58	58	58	58	58	58	58	58	58	580
16																0	58	58	58	58	58	58	58	58	58	522
17																	0	58	58	58	58	58	58	58	58	464
18																		0	58	58	58	58	58	58	58	406
19																			0	58	58	58	58	58	58	348
20																				0	58	58	58	58	58	290
21																				0	0	58	58	58	58	232
22																						0	58	58	58	174
23																							0	58	58	116
24																								0	58	58
25																									0	0
Alightings	0	58	116	174	232	290	348	406	464	522	580	638	696	754	812	870	928	986	1044	1102	1160	1218	1276	1334	1392	

6.7 Deciding on Stop Elimination and Express Services

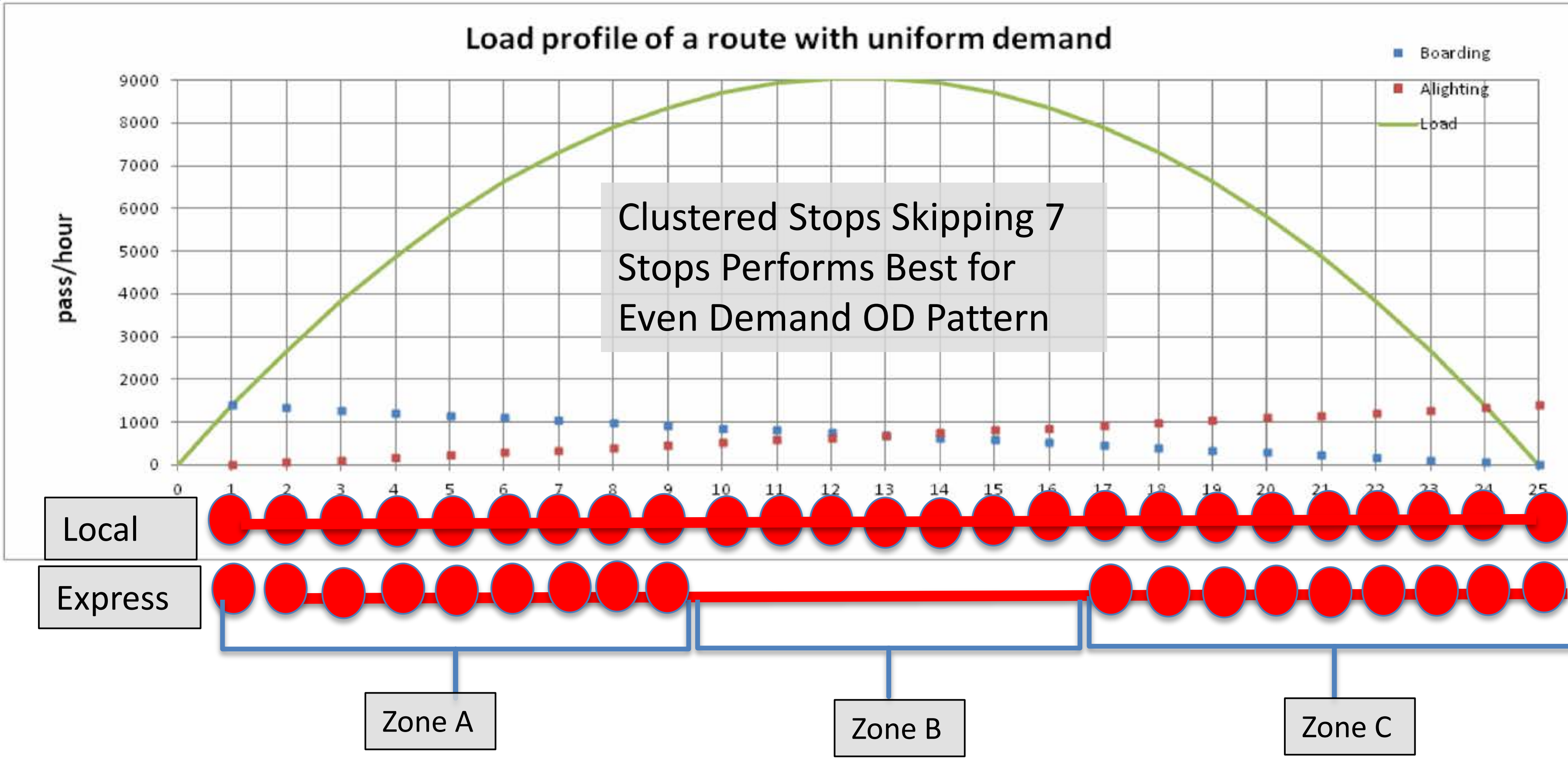
Type I: Even demand between all OD pairs

Bus Stop	Boarding	Alighting	Load
0			0
1	1392	0	1392
2	1334	58	2668
3	1276	116	3828
4	1218	174	4872
5	1160	232	5800
6	1102	290	6612
7	1044	348	7308
8	986	406	7888
9	928	464	8352
10	870	522	8700
11	812	580	8932
12	754	638	9048
13	696	696	9048
14	638	754	8932
15	580	812	8700
16	522	870	8352
17	464	928	7888
18	406	986	7308
19	348	1044	6612
20	290	1102	5800
21	232	1160	4872
22	174	1218	3828
23	116	1276	2668
24	58	1334	1392
25	0	1392	0
Total/MAX	17400	17400	9048



Existing Service Frequency = 9048 (MaxLoad)/150 (bus capacity) = 61.32

6.7 Deciding on Stop Elimination and Express Services



Passengers traveling within zone A or Zone C can take either local or express.

No change in costs and benefits

Passengers traveling from A to C or C to A will all take Express.

Big benefit

Passengers traveling between A and B or B and C lose 50% of frequency

Additional cost varies with frequency

Type I: Even demand between all OD pairs: 7 stops skipped by Express:

Origin Destination Matrix for Uniform Demand on a Bus Route

Zone/Stop		Zone A									Zone B							Zone C								
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
	1	0	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58
	2		0	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58
	3			0	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58
	4				0	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58
Zone A	5					0	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58
	6						0	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58
	7							0	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58
	8								0	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58
	9									0	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58
	10										0	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58
	11											0	58	58	58	58	58	58	58	58	58	58	58	58	58	58
	12												0	58	58	58	58	58	58	58	58	58	58	58	58	58
Zone B	13													0	58	58	58	58	58	58	58	58	58	58	58	58
	14														0	58	58	58	58	58	58	58	58	58	58	58
	15															0	58	58	58	58	58	58	58	58	58	58
	16																0	58	58	58	58	58	58	58	58	58
	17																	0	58	58	58	58	58	58	58	58
	18																		0	58	58	58	58	58	58	58
	19																			0	58	58	58	58	58	58
	20																				0	58	58	58	58	58
Zone C	21																				0	0	58	58	58	58
	22																						0	58	58	58
	23																							0	58	58
	24																								0	58
	25																									0
Alightings		0	58	116	174	232	290	348	406	464	522	580	638	696	754	812	870	928	986	1044	1102	1160	1218	1276	1334	1392

- Yellow: Demand split between Express & Local
- Pink: Demand captured entirely by Local
- Blue: Demand captured entirely by Express

Relative size of the boxes (demand per service) varies with the number of stops skipped:

Even demand between all OD pairs: Benefits only

Limited Route Demand Distribution								Benefits			
Bus stop use pattern			passenger demand division				frequency of limited	benefits for limited service			Total Benefit
limited and local stops	local stops only	Limited and local stops	limited	shared	local	total	bus/h	time savings per bus	passenger hours of benefit	bus hours saved	US$/h
11	3	11	7018	6380	4002	17400	46.79	1.500	175.45	1.170	1176
10	5	10	5800	5220	6380	17400	38.7	2.5	242	1.61	1619
9	7	9	4698	4176	8526	17400	31.3	3.5	274	1.83	1836
8	9	8	3712	3248	10440	17400	24.7	4.5	278	1.86	1865
7	11	7	2842	2436	12122	17400	18.9	5.5	261	1.74	1745
6	13	6	2088	1740	13572	17400	13.9	6.5	226	1.51	1516
5	15	5	1450	1160	14790	17400	9.7	7.5	181	1.21	1214
4	17	4	928	696	15776	17400	6.2	8.5	131	0.88	881
3	19	3	522	348	16530	17400	3.5	9.5	83	0.55	554
2	21	2	232	116	17052	17400	1.5	10.5	41	0.27	272
1	23	1	58	0	17342	17400	0.4	11.5	11	0.07	74

As demand varies depending on how many stops are skipped, so does the frequency. Without considering costs (drop in frequency), benefits are maximized when 9 stops are skipped.

6.7 Deciding on Stop Elimination and Express Services

Type I: Even demand between all OD pairs: Benefits net of costs

Net Benefits of Alternative Skip Stop Patterns									
Limited Route Demand Distribution				Benefits	Costs				Net Benefit
Bus Stop Use Pattern			Frequency of Limited	Total Benefit	Cost of Original Service	Cost of Express	Cost of Local	Net Cost of Express	Net Benefit
Segment A: Limited and Local Stops	Segment B: Local Stops Only	Segment C: Limited and Local Stops	bus/h	US$/h	US$/h	US$/hr	US$/hr	US$/hr	US$/hr
11	3	11	46.79	1176	3760	2802	1433	475	700
10	5	10	38.7	1619	3760	2330	1624	194	1425
9	7	9	31.3	1836	3760	1981	1874	95	1741
8	9	8	24.7	1865	3760	1731	2159	130	1735
7	11	7	18.9	1745	3760	1559	2460	258	1487
6	13	6	13.9	1516	3760	1447	2757	444	1072
5	15	5	9.7	1214	3760	1378	3036	654	560
4	17	4	6.2	881	3760	1341	3282	863	18
3	19	3	3.5	554	3760	1323	3485	1048	-494
2	21	2	1.5	272	3760	1317	3636	1192	-920
1	23	1	0.4	74	3760	1315	3729	1284	-1209

When costs are included, skipping 7 stops is optimal
(Given a set of input assumptions)

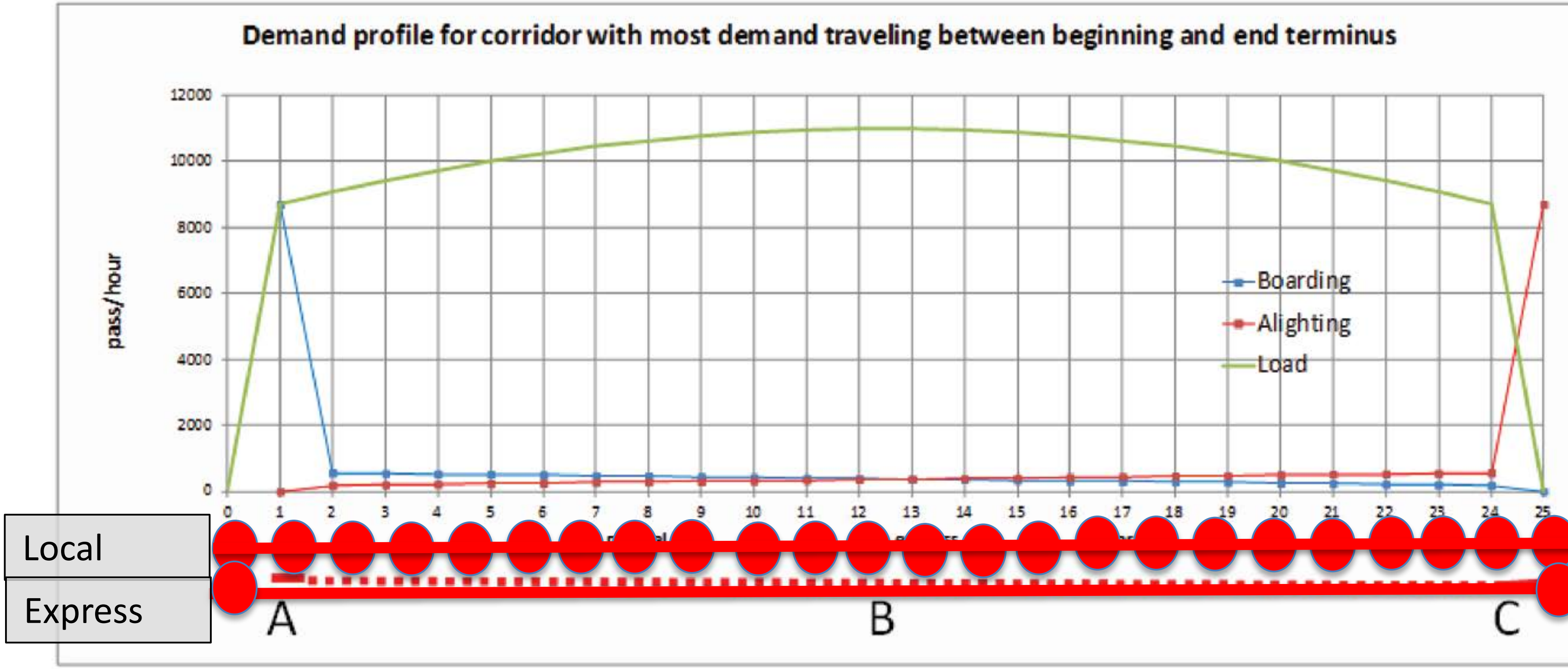
6.7 Deciding on Stop Elimination and Express Services

Type I: Even demand between all OD pairs: Conclusions

- Time saved on Express (from skipping stops) must be significantly greater than the time lost to both the Express and Local passengers (from lower frequency)
- Time saved from skipping stops doesn't vary with demand, but time lost due to lower frequencies is much lower on high demand corridors.
- Thus, the benefits of adding the Express increase with higher demand on the corridor
- In 'even demand' scenario, Express service needs to make clusters of local stops to collect enough demand.

6.7 Deciding on Stop Elimination and Express Services

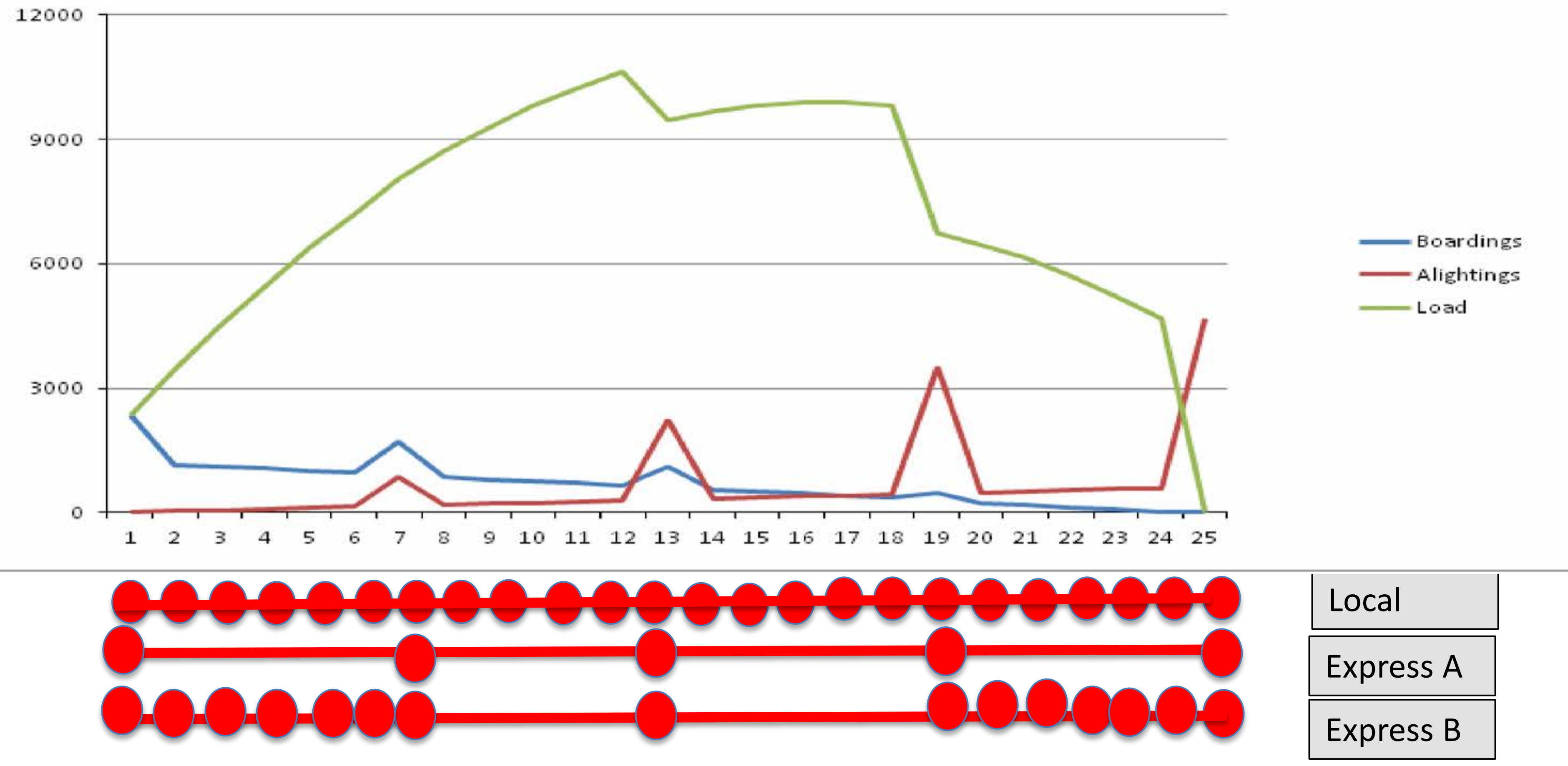
Type II: Trunk-Feeder Services



Express service should stop only at the transfer terminal and downtown with no intervening stops

6.7 Deciding on Stop Elimination and Express Services

Type III: Demand clustered at a few popular locations



Express Route B performs better than Express A in most OD profiles

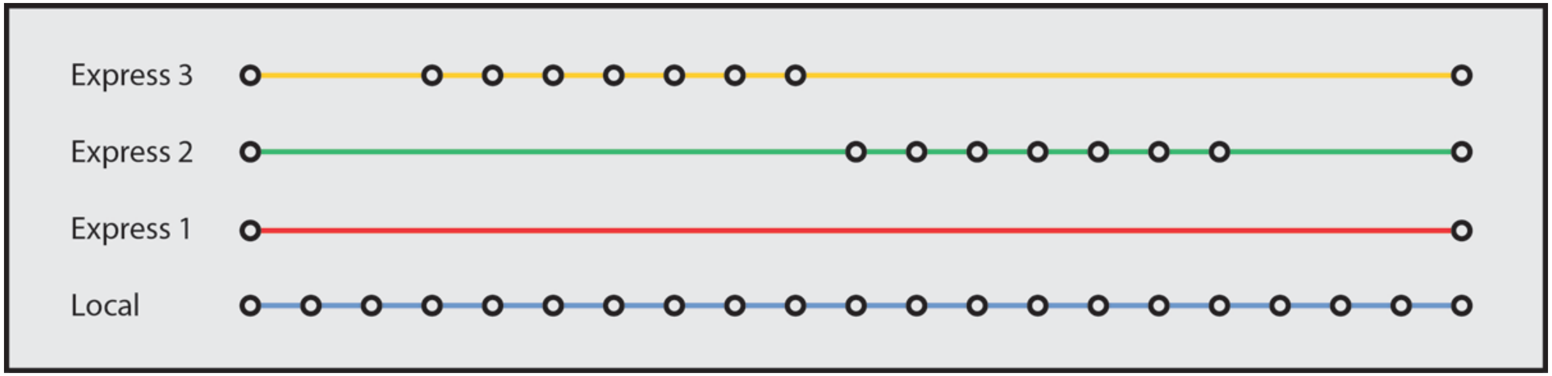
6.7 Deciding on Stop Elimination and Express Services

Type IV: Constantly falling loads

Optimal service design for constantly falling loads (for example, from downtown to the outskirts of town).

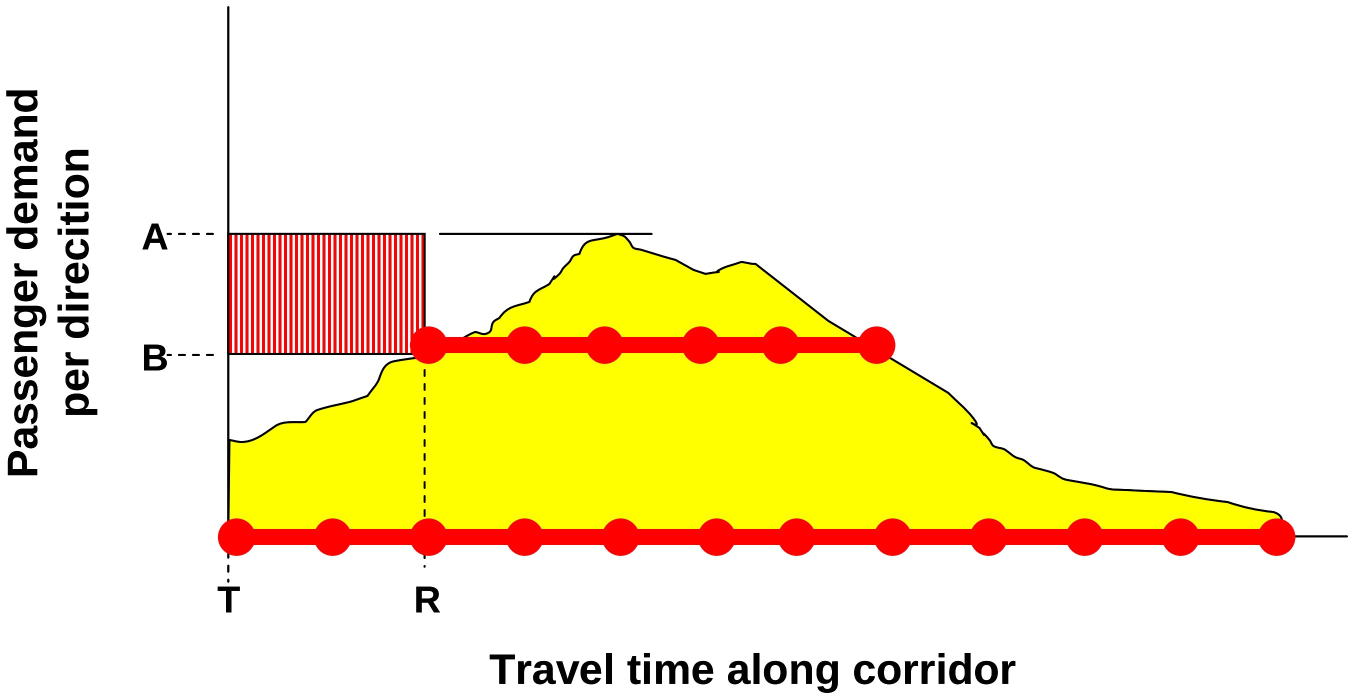
6.7 Deciding on Stop Elimination and Express Services

Type V: Extremely Heavy Demand (aka TransMilenio)



If demand on a corridor is high enough, it will make sense to keep splitting the demand among additional routes.
There will be a sub-set of passengers for which many of the previously discussed profiles will be optimal.

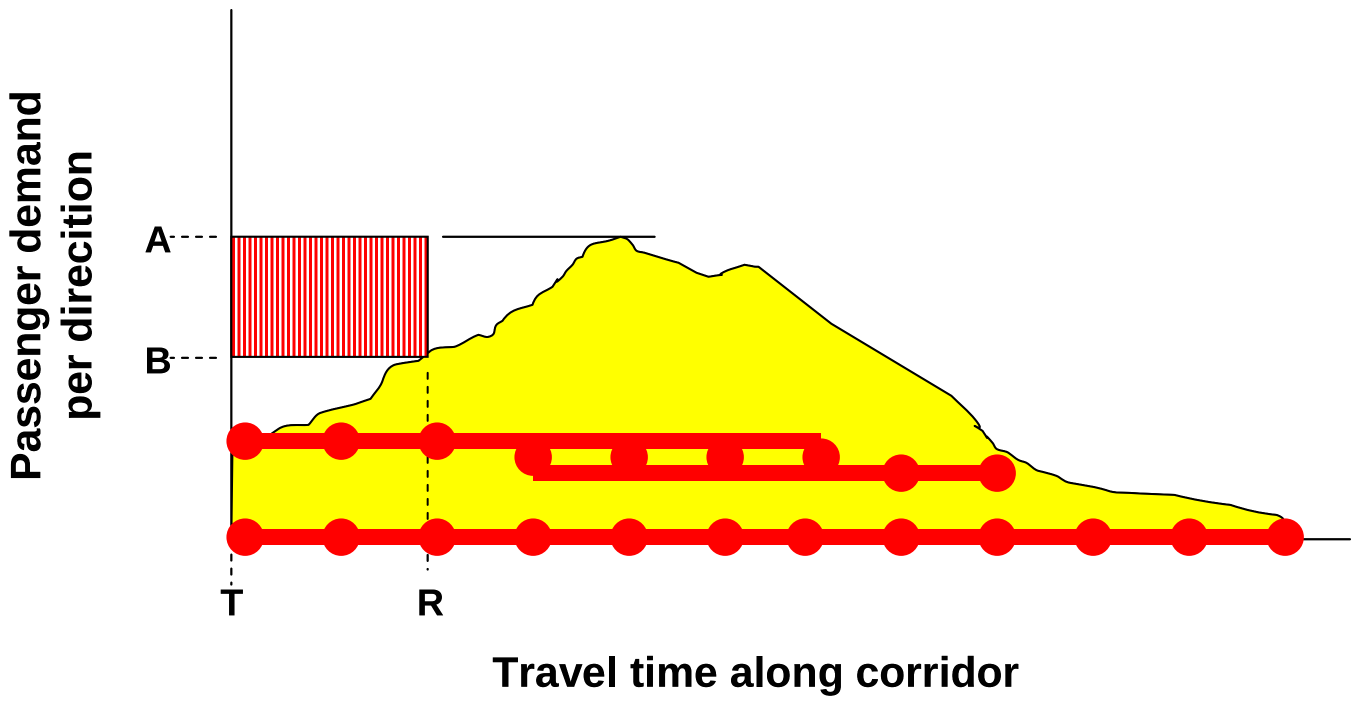
Create ‘early return’ service overlapping a trunk service through peak demand section of a route



6.8 Creating New Routes and Combining Old Routes

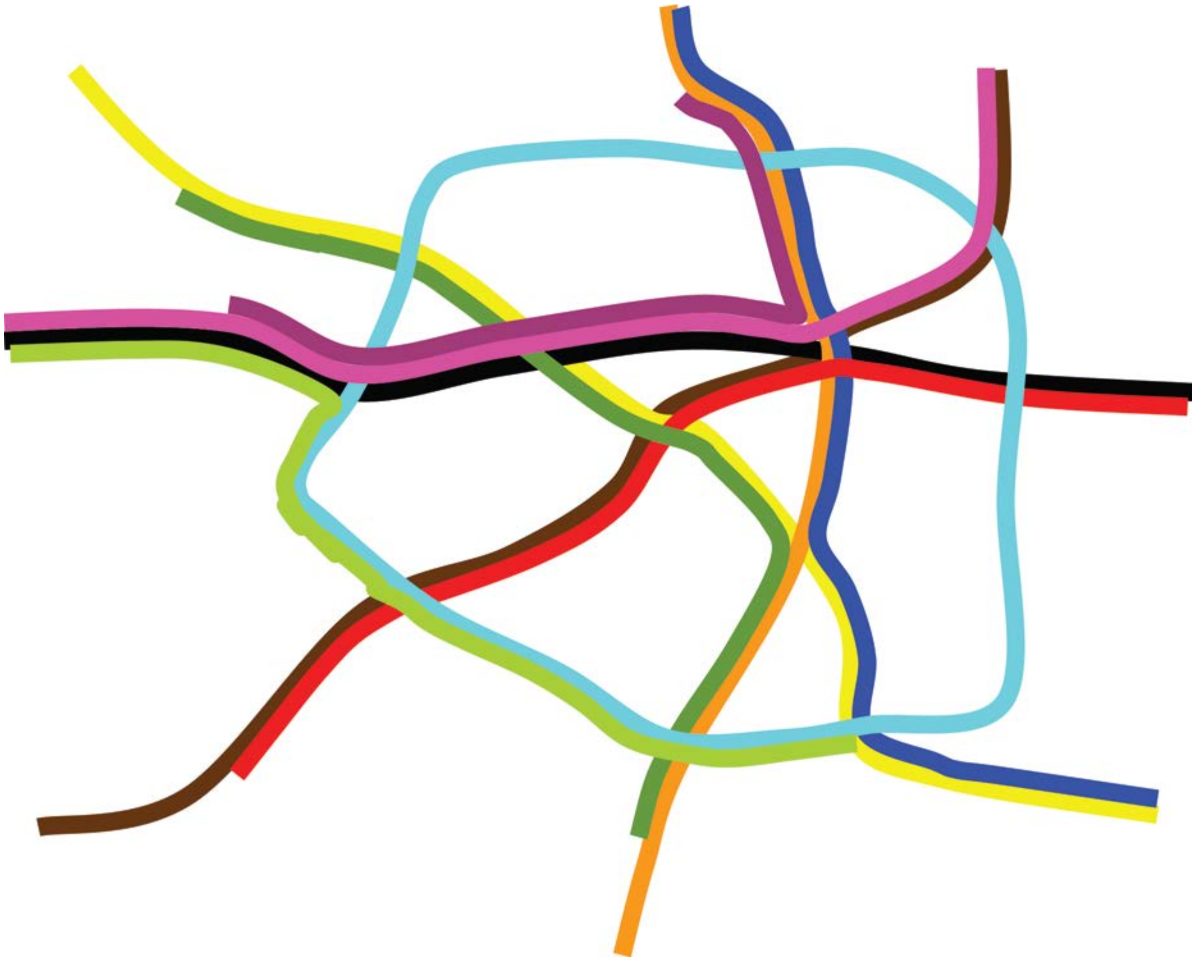
Shortening routes to improve regularity of service:

Doubles frequency in highest demand section of the corridor



6.8 Creating New Routes and Combining Old Routes

When to combine routes?



Metro systems have linear routes with high transfer volumes in huge transfer stations. BRT systems can just add inter-corridor services. But when?

6.8 Creating New Routes and Combining Old Routes

Connecting Services: When does it make sense?

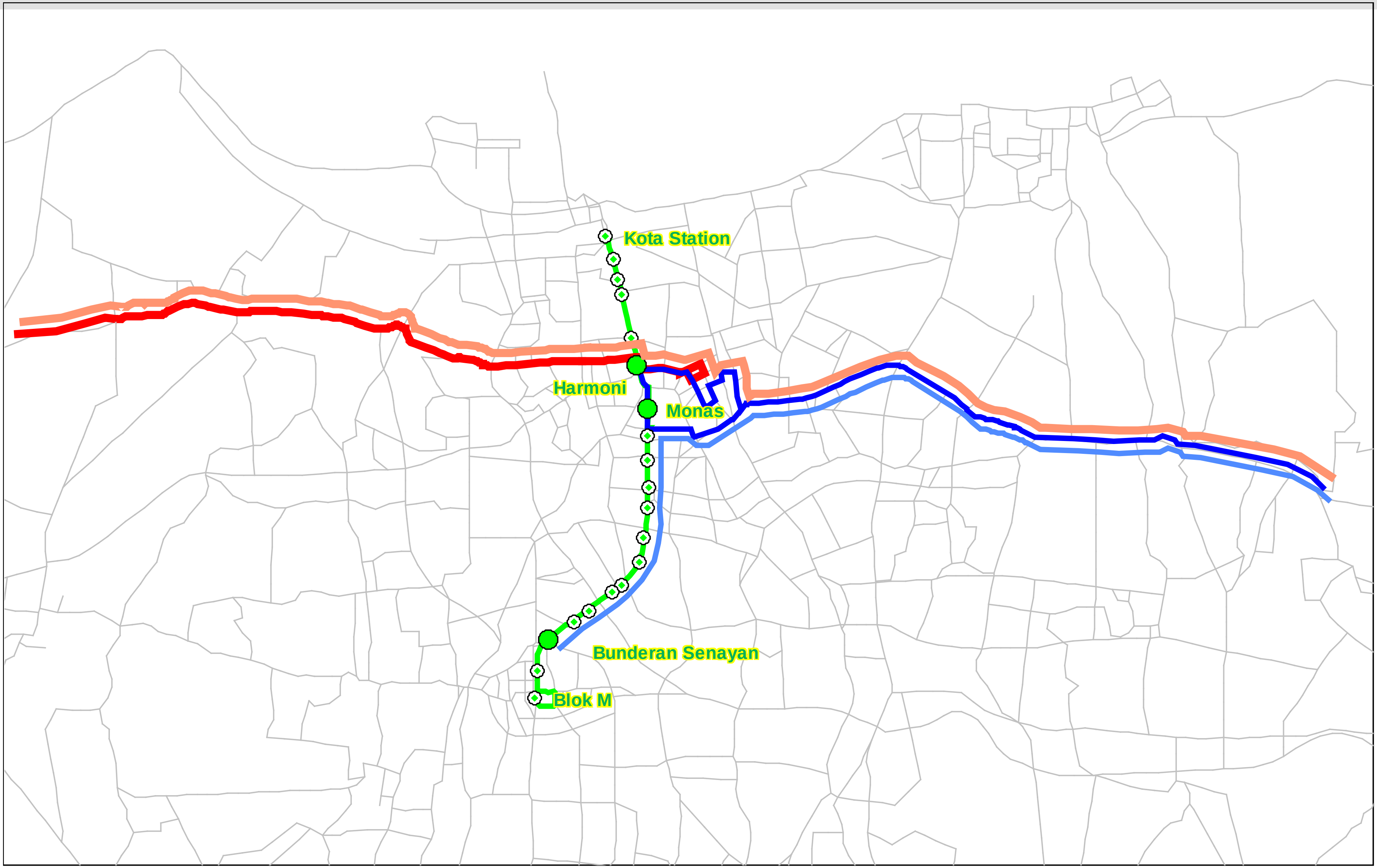
Many bus services in the US run on a grid pattern. Adding services that avoid transfers on highest volume routes make sense if the volumes are high enough. In the US they rarely are.

6.8 Creating New Routes and Combining Old Routes

A huge transfer bottleneck in TransJakarta at Harmony Station is evidence of a need for more inter-corridor routes. But which ones and how many?

6.8 Creating New Routes and Combining Old Routes

Gradually more routes were added. Methodology not yet developed



THANK YOU

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