Modeling Public Transport in the Arlington Co. Tour-based Travel Model

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Agenda

"In this presentation, we highlight the key steps, methods, and assumptions that went into the creation of the transit skims and the transit assignment process."

- Introduction to PT in CUBE: key concepts
- Approach for the Arlington PT Model
- Coding of the Arlington PT System
- PT Skimming and Assignment
- Calibration
- Potential Future Improvements
  - Note on PT Crowding Auxiliary Process

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Introduction to PT in CUBE: Trnbuild vs Public Transport

Trnbuild

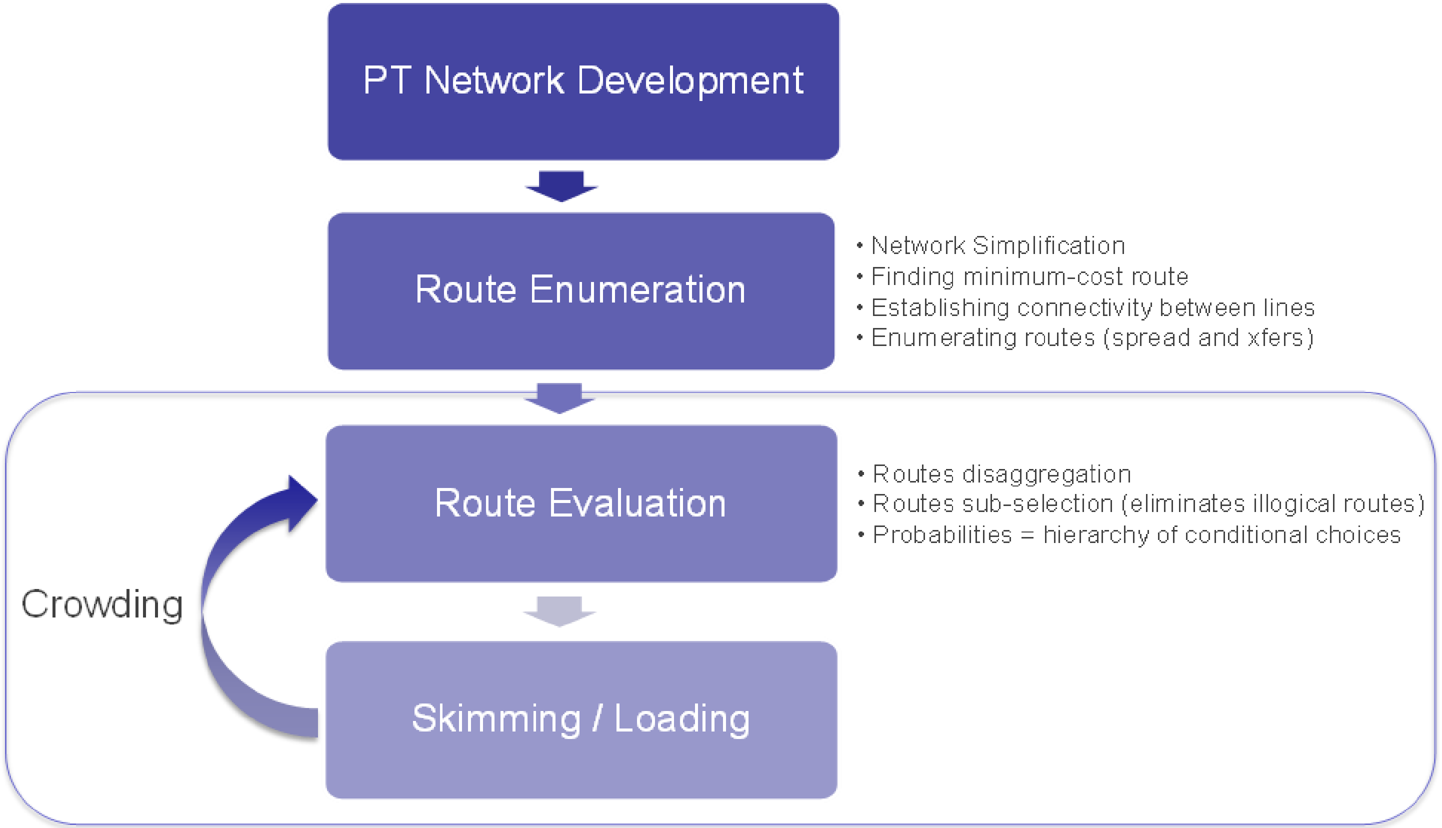
- Simplified approach based on best-path
- Not supported* by Bentley in future releases

Public Transport

- Algorithm based on multi-routing
- Capability to capture the complexity of the PT system and passengers' behavior
- Requires a different approach being a different program
- Supported* by Bentley

*Software support = help/technical-support, maintenance, active development

Introduction to PT in CUBE: Algorithm



- **Heuristic Algorithm**: feasible solution close to an "optimal solution" by using a sequence of rules
- **Probabilistic Algorithm** (route evaluation): probabilities at each decision point along the route and conditional probability for the entire route

Introduction to PT in CUBE: Alternative Approaches

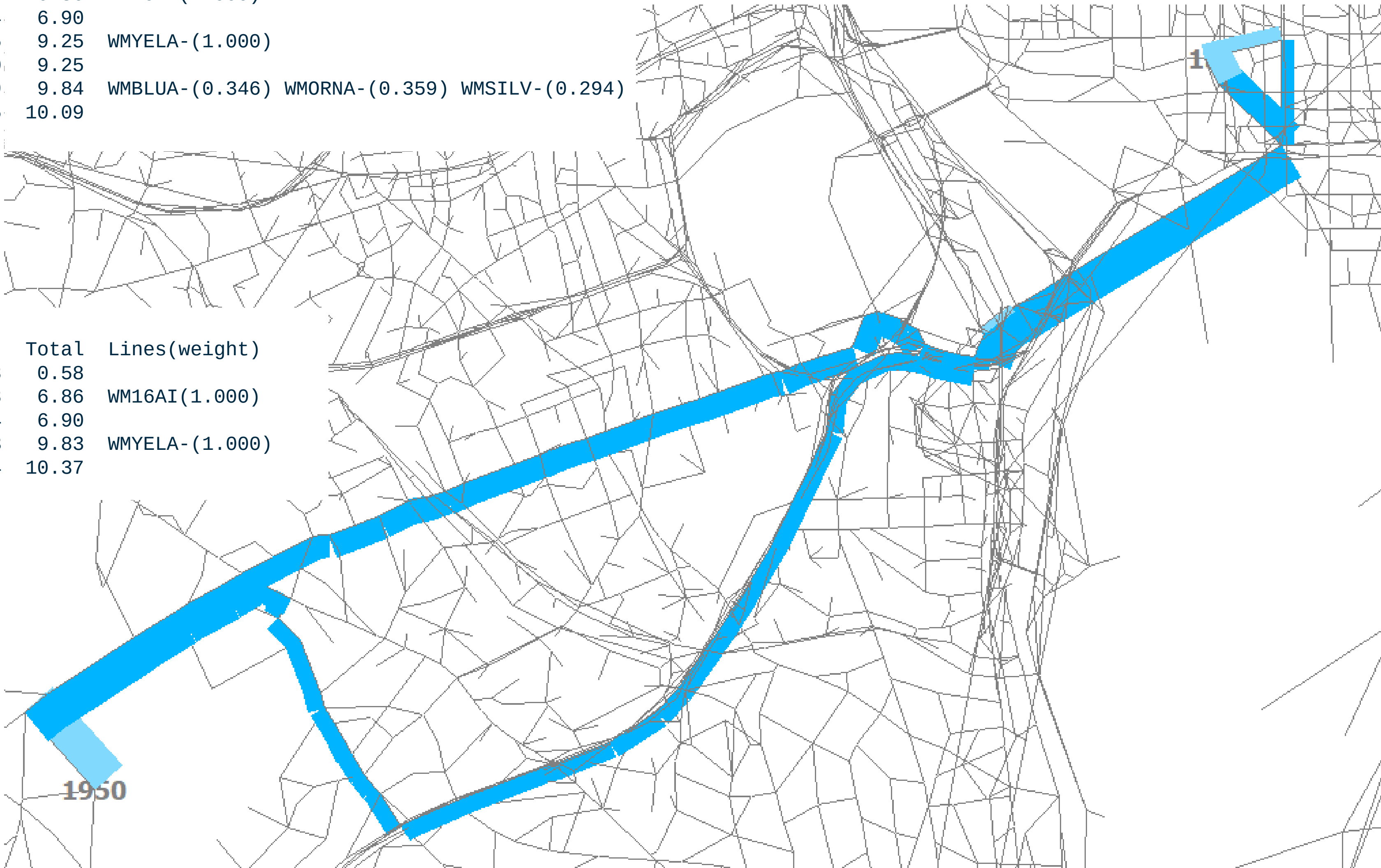
- Headway/frequency-based vs timetable/schedule-based
- Multi-user class vs single-user class
- Multi-routing (vs best-path)
- Uncongested assignment vs crowding
- Fares vs no-fares
- Frequency and generalized cost to destination (service-frequency-and-cost) vs frequency only (service-frequency)
- Alternative approaches for level of network coding detail for:
  - NT-Legs generation
  - Coding of PnR, KnR/TNCnR
- Alternative approaches for coding transit travel times

Introduction to PT in CUBE: Multi-Routing Example

```
REval Route(s) from Origin 1950 to Destination 13

N:  1950 Mode  WaitA  TimeA Actual B/XPen Percvd   Dist  Total  Lines(weight)
-> 34051  101      -  11.60  11.60      -  12.76   0.58   0.58
-> 30204    1  13.26  32.02  56.88   4.50  65.19   6.28   6.86  WM16AI(1.000)
->  8055  351      -   0.54  57.42      -  65.89   0.04   6.90
->  8037    3   4.00   0.97  62.38   4.10  74.96   2.35   9.25  WMYELA-(1.000)
->  8037    -      -   0.00  62.38      -  74.96   0.00   9.25
->  8070    3   1.44   0.54  64.36   4.10  81.03   0.59   9.84  WMBLUA-(0.346) WMORNA-(0.359) WMSILV-(0.294)
->    13  203      -   5.00  69.36      -  86.53   0.25  10.09
Mode  TimeA   Dist IWaitA XWaitA
   1  32.02   6.28  13.26   0.00
   3   1.50   2.94   0.00   5.44
 101  11.60   0.58
 203   5.00   0.25
 351   0.54   0.04
Fare=   3.75
Probability=0.6918

N:  1950 Mode  WaitA  TimeA Actual B/XPen Percvd   Dist  Total  Lines(weight)
-> 34051  101      -  11.60  11.60      -  12.76   0.58   0.58
-> 30204    1  13.26  32.02  56.88   4.50  65.19   6.28   6.86  WM16AI(1.000)
->  8055  351      -   0.54  57.42      -  65.89   0.04   6.90
->  8036    3   4.00   3.35  64.77   4.10  77.35   2.93   9.83  WMYELA-(1.000)
->    13  203      -  10.80  75.57      -  89.23   0.54  10.37
Mode  TimeA   Dist IWaitA XWaitA
   1  32.02   6.28  13.26   0.00
   3   3.35   2.93   0.00   4.00
 101  11.60   0.58
 203  10.80   0.54
 351   0.54   0.04
Fare=   3.75
Probability=0.3082
```

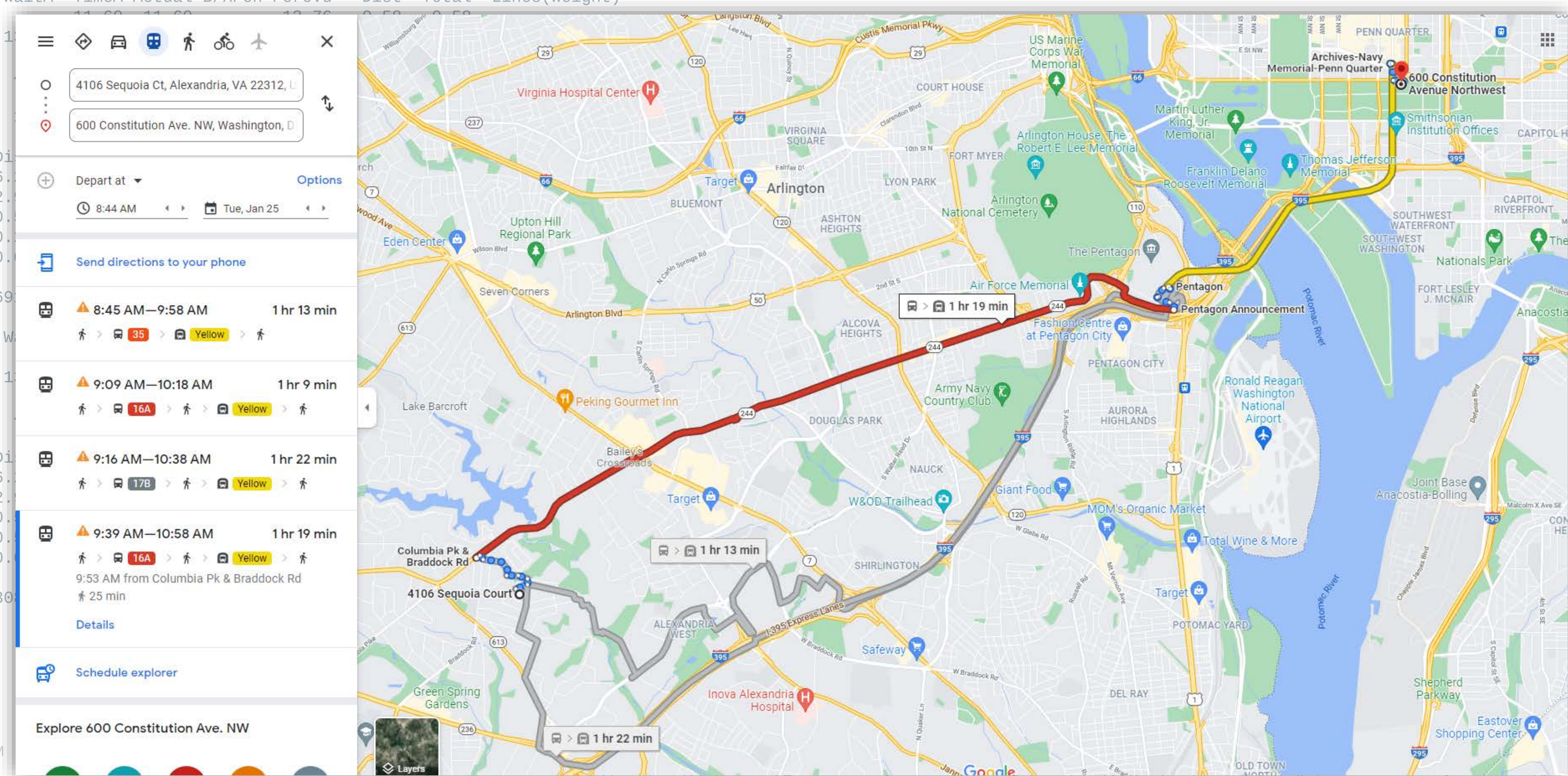


Introduction to PT in CUBE: Multi-Routing Example

```
REval Route(s) from Origin 1950 to Destination 13

N:  1950 Mode  WaitA  TimeA Actual B/XPen Percvd   Dist  Total  Lines(weight)
-> 34051  101
-> 30204    1  1
->  8055  351
->  8037    3
->  8037    -
->  8070    3
->    13  203
Mode  TimeA   Di
   1  32.02   6.
   3   1.50   2.
 101  11.60   0.
 203   5.00   0.
 351   0.54   0.
Fare=   3.75
Probability=0.69

N:  1950 Mode   W
-> 34051  101
-> 30204    1  1
->  8055  351
->  8036    3
->    13  203
Mode  TimeA   Di
   1  32.02   6.
   3   3.35   2.
 101  11.60   0.
 203  10.80   0.
 351   0.54   0.
Fare=   3.75
Probability=0.30
```



Introduction to PT in CUBE: Multi-Routing - Low-Spread Balance

Why **multi-routing**?

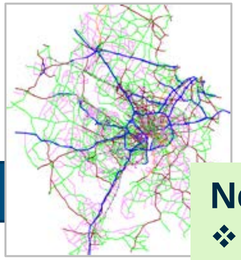
- Time aggregation: not simulating every single departure time but simulation period of one or more hours → proportions based on frequency
- Zoning system aggregation: path creation between zones not single buildings (aggregating spatial locations)
- User behavior aggregation: choices depending on user classes not single individuals

Why **low-spread** → closer to best-path?

- ↓ Runtime (increases with spread due to many route-variations)
- ↓ File sizes
- Simplification of the PT system: consolidation of modes/lines/vehicles already including multiple sub-routes
- Multiple user classes to simulate different preferences, rather than higher spread
- The more we disaggregate, the more we reduce spread → closer to single best-path (obtained with 0-spread in PT)

Approach for the Arlington PT Model

Working catalog: "Cat_Arlington_PT_v08.cat"
Documentation: "PT_Arlington_Ref_Guide_v08.02.docx"



- Master Network File (.NET)
- PT Lines (.LIN)
- PT System Description
- Wait and Crowd Curves
- Factors and Parameters

PT Matrices for AM, MD, PM, NT:

❖ Origin → Destination:
- Non-motorized access/egress — uc1
- PnR access — uc2
- KnR/TNCnR access — uc2

❖ Destination → Origin
- Non-motorized access/egress — uc1
- PnR egress — uc3
- KnR/TNCnR egress — uc3

Network Preparation

❖ HW: updating attributes to calculate transit speeds

❖ PT Lines:
- pre-process and combine line files
- remove RUNTIME for buses (kept for rail)
- add DWELL_TIME
- add OPERATOR
- generate lines by time period: AM, MD, PM, NT

NT-Legs
- GENERATION for non-motorized based on sub-mode and short vs long
- From input table for PnR and KnR/TNCnR based on lot (TAZ) - stop

Fares
- Input fare systems by operator
- Generation of fare matrices

PT Skimming
PK, OP

PT Assignment
AM, MD, PM, NT

PT Crowding calculations

ANALYSIS AND CALIBRATION:

❖ Lines and Stops analysis

❖ NT-Legs analysis
- By-zone and by-stop
- Walk index

❖ Disconnection analysis

❖ Transit time analysis

❖ Walk time analysis

❖ Wait time analysis

❖ Fares analysis

❖ Transfers analysis

❖ Volume's analysis

❖ Crowding analysis

❖ Select Link/Station analysis

❖ Routing analysis

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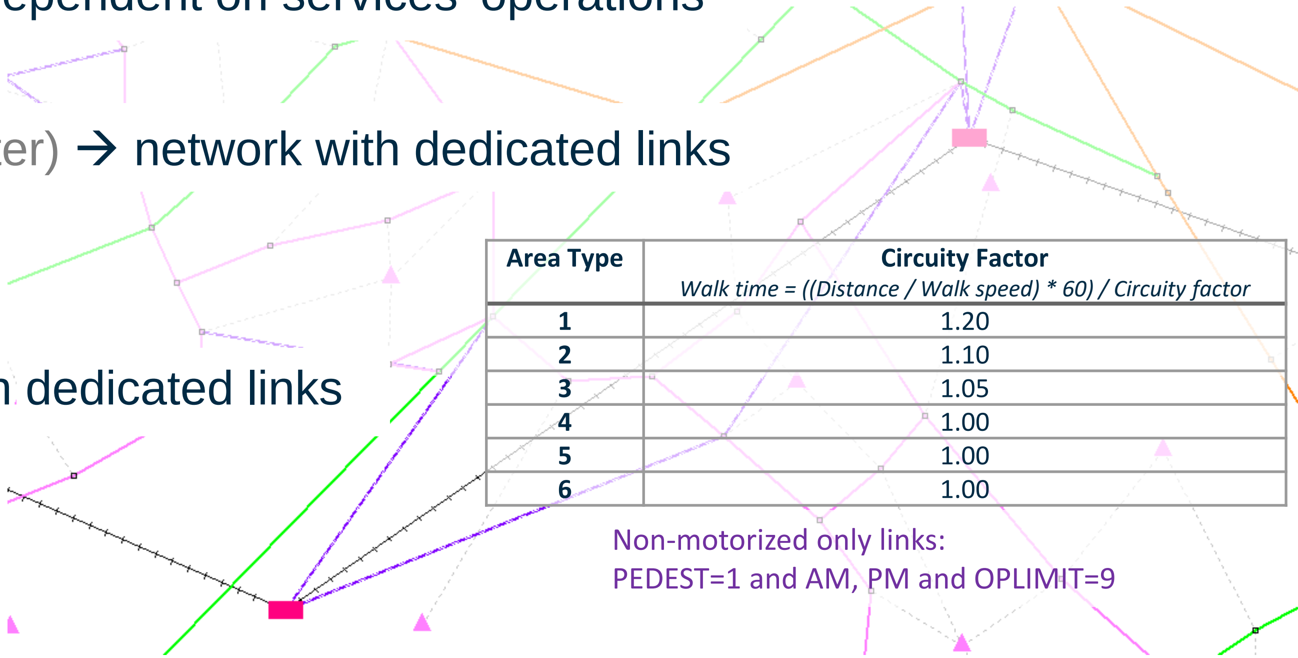
Coding of the Arlington PT System: Non-Transit

- Single Master Network → supporting infrastructures for HW, Transit and Non-Transit modes
- Non-Transit Legs are "infrastructural", i.e., do not dependent on services' operations

- Non-motorized: walk (bike, scooter, e-bike, e-scooter) → network with dedicated links
  - Access from origin to stop nodes
  - Egress from stop nodes to destination
- Walk transfers between stop nodes → network with dedicated links



Area Type	Circuity Factor *Walk time = ((Distance / Walk speed) * 60) / Circuity factor*
1	1.20
2	1.10
3	1.05
4	1.00
5	1.00
6	1.00

- Motorized: PnR, KnR/TNCnR → extra links not needed but Stations.DBF → time + extra time
  - Access from PnR lot or KnR/TNCnR area to stop node
  - Egress from stop node to PnR lot or KnR/TNCnR area

Coding of the Arlington PT System: Non-Transit

Mode	Name	Long-name	MinDist [miles]	MaxDist [miles]	Slack [miles]	Max n. NTLegs	
Active NT modes access (walk, bicycle, etc.)							
101	BWalkAccS	Bus Walk Access - Short	-	1	-	8	
102	BWalkAccL	Bus Walk Access - Long	1	3	1	2	
103	MRWalkAccS	Metrorail Walk Access - Short	-	1.5	-	4	
104	MRWalkAccL	Metrorail Walk Access - Long	1.5	3	1	2	GENERATE
105	CRWalkAccS	Comm Rail Walk Access - Short	-	1.5	-	8	
106	CRWalkAccL	Comm Rail Walk Access - Long	1.5	3	1	2	
107	LRWalkAccS	Light Rail BRT/LRT Walk Access - Short	-	1	-	5	
108	LRWalkAccL	Light Rail BRT/LRT Walk Access – Long	1	2	1	2	
Park and Ride or Kiss and Ride access							
151	PnRBusAcc	PnR Bus Access	-	-	-	1	
153	PnRMRailAcc	PnR MetroRail Access	-	-	-	1	Table
154	PnRCRailAcc	PnR Commuter Rail Access	-	-	-	1	
155	PnRLRAcc	PnR Light Rail BRT/LRT Access	-	-	-	1	
Active NT modes egress (walk, bicycle, etc.)							
201	BWalkEgrS	Bus Walk Egress - Short	-	1	-	8	
202	BWalkEgrL	Bus Walk Egress - Long	1	3	1	2	
203	MRWalkEgrS	Metrorail Walk Egress - Short	-	1.5	-	4	
204	MRWalkEgrL	Metrorail Walk Egress - Long	1.5	3	1	2	GENERATE
205	CRWalkEgrS	Comm Rail Walk Egress - Short	-	1.5	-	8	
206	CRWalkEgrL	Comm Rail Walk Egress - Long	1.5	3	1	2	
207	LRWalkEgrS	Light Rail BRT/LRT Walk Egress - Short	-	1	-	5	
208	LRWalkEgrL	Light Rail BRT/LRT Walk Egress – Long	1	2	1	2	
Park and Ride or Kiss and Ride egress							
251	PnRBusEgr	PnR Bus Egress	-	-	-	1	
253	PnRMRailEgr	PnR MetroRail Egress	-	-	-	1	Table
254	PnRCRailEgr	PnR Commuter Rail Egress	-	-	-	1	
255	PnRLREgr	PnR Light Rail BRT/LRT Egress	-	-	-	1	
Transfers NT modes							
300	WalkXfr	Walk Transfers	-	0.5	0.1	2	GENERATE
351	PnRXfr	Transfers at PnR/KnR stations	-	-	-	1	Table

Coding of the Arlington PT System: Transit (1)

Actual TRANTIME (buses) = calculated speed based on link and sub-mode * Factor_1 * Factor_2 + Dwell Time

- Factor_1 = depending on the transit mode
- Factor_2 = depending on the link area type and facility type

Actual TRANTIME (reserved) = [calculated speed based on link attribute + Dwell Time] → RUNTIME

Mode	Long-name	TRANSIT SPEED			FACTORS by MODE (Factor_1)		Dwell Time [minutes]	
		Skimming		Assignment by period AM, PM = Peak periods MD, NT = Off-Peak periods	Peak periods	Off-Peak periods	Peak periods	Off-Peak periods
		Peak	Off-Peak					
1	Local Metrobus	PKSPEED = *f(area type, link type)*	75% FFSPEED + 25% PEAKSPEED	Congested speed for mixed traffic from HW assignment	0.90	0.95	0.30	0.25
2	Express Metrobus	PKSPEED = *f(area type, link type)*	75% FFSPEED + 25% PEAKSPEED	Congested speed for mixed traffic from HW assignment	1.00	1.00	1.00	0.75
3	Metrorail	RAILSPEED attribute	RAILSPEED attribute	RAILSPEED attribute	-	-	2.00	1.50
4	Commuter Rail	RAILSPEED attribute	RAILSPEED attribute	RAILSPEED attribute	-	-	4.00	3.00
5	Light Rail Transit	RAILSPEED attribute	RAILSPEED attribute	RAILSPEED attribute	-	-	1.00	0.75
6	Other Local Bus in WMATA Service Area	PKSPEED = *f(area type, link type)*	75% FFSPEED + 25% PEAKSPEED	Congested speed for mixed traffic from HW assignment	0.90	0.95	0.35	0.25
7	Other Express Bus in WMATA Service Area	PKSPEED = *f(area type, link type)*	75% FFSPEED + 25% PEAKSPEED	Congested speed for mixed traffic from HW assignment	0.90	0.95	0.80	0.70
8	Other Local Bus beyond WMATA Service Area	PKSPEED = *f(area type, link type)*	75% FFSPEED + 25% PEAKSPEED	Congested speed for mixed traffic from HW assignment	0.90	0.95	0.30	0.20
9	Other Express Bus beyond WMATA Service Area	PKSPEED = *f(area type, link type)*	75% FFSPEED + 25% PEAKSPEED	Congested speed for mixed traffic from HW assignment	0.95	0.95	0.40	0.30
10	Bus Rapid Transit and Streetcar	"RAILSPEED" attribute	"RAILSPEED" attribute	"RAILSPEED" attribute	-	-	1.00	0.75

Coding of the Arlington PT System: Transit (2)

Actual TRANTIME (buses) = calculated speed based on link and sub-mode * Factor_1 * Factor_2 + Dwell Time

- Factor_1 = depending on the transit mode
- Factor_2 = depending on the link area type and facility type

Actual TRANTIME (reserved) = [calculated speed based on link attribute + Dwell Time] → RUNTIME

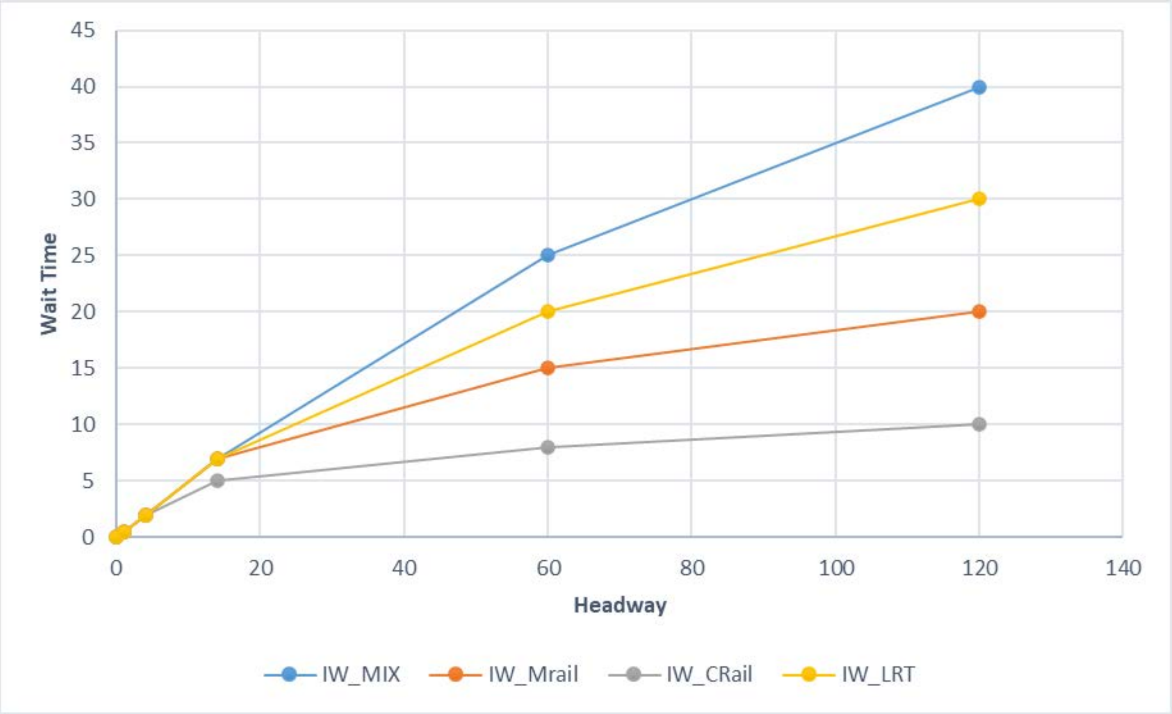
Facility Type	Area Type 1	Area Type 2	Area Type 3	Area Type 4	Area Type 5	Area Type 6
Peak periods Factor_2						
0 (centr conn)	1	1	1	1	1	1
1 (freeway)	0.8	0.8	0.8	0.8	0.8	0.8
2 (maj art)	0.9	0.8	0.8	0.8	0.8	0.8
3 (min art)	1	1	0.9	0.9	0.8	0.8
4 (collector)	1	1	1	0.9	0.8	0.8
5 (expressway)	0.9	0.8	0.8	0.8	0.8	0.8
6 (ramp)	0.8	0.8	0.8	0.8	0.8	0.8
7 (local)	1	1	1	1	1	1
Off-Peak periods Factor_2						
0 (centr conn)	1	1	1	1	1	1
1 (freeway)	0.8	0.8	0.8	0.8	0.8	0.8
2 (maj art)	1	1	0.9	0.8	0.9	0.8
3 (min art)	1	1	0.9	0.9	0.9	0.8
4 (collector)	1	1	1	0.9	0.9	0.8
5 (expressway)	1	1	0.9	0.8	0.8	0.8
6 (ramp)	0.8	0.8	0.8	0.8	0.8	0.8
7 (local)	1	1	1	1	1	1

Coding of the Arlington PT System: Wait Curves

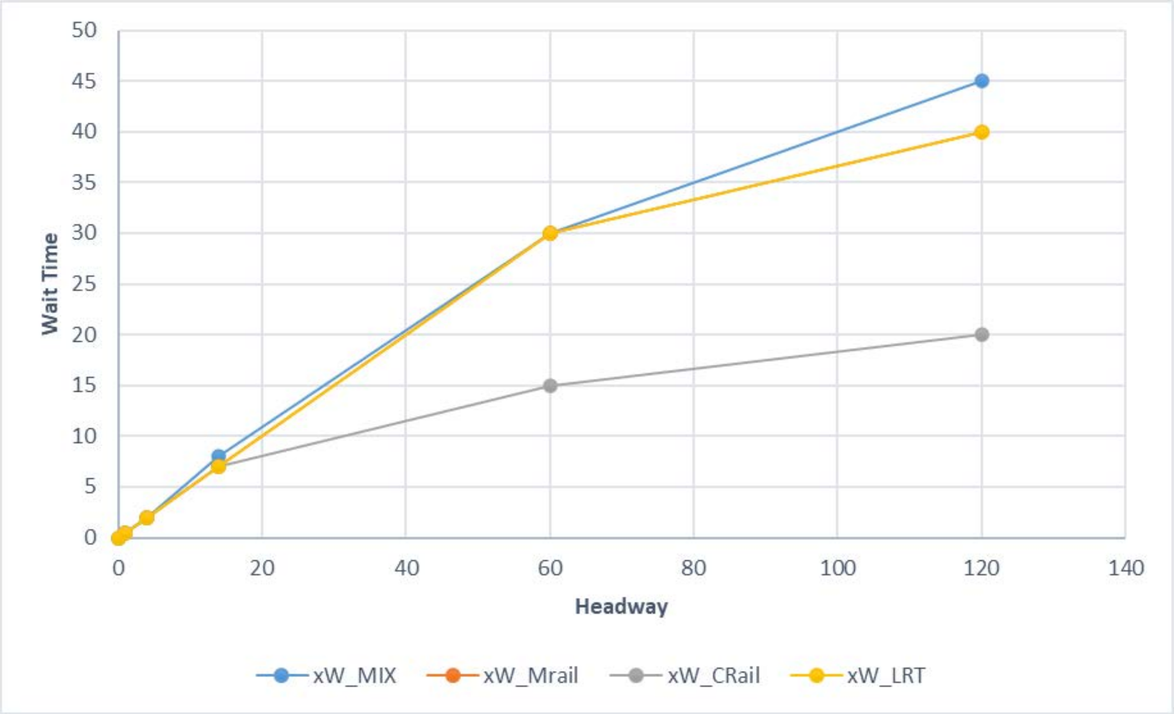
Wait curves applied by stop-node → wait time = f(cumulative frequency of the services available at the stop node)

- MIX – MIX Buses – PT modes 1, 2, 6, 7, 8, 9
- MRail – MetroRail – PT mode 3
- CRail – CommuterRail – PT mode 4
- LRT – LRT and BRT – PT modes 5, 10

Initial wait curves



Transfer wait curves



PT Skimming and Assignment: Factor File

Route Enumeration

SPREAD = MAX(GCost(MinRoute)* SPREADFACT, GCost(MinRoute) + SPREADCONST)

Parameter	UC 1	UC 2	UC 3
SPREADFUNC	1	1	1
SPREADFACT	1.10	1.05	1.05
SPREADCONST [min]	2	1	1

Parameter	UC 1	UC 2	UC 3
AONMAXFERS	5	3	3
MAXFERS	3	2	2
EXTRAXFERS1	1	1	1
EXTRAXFERS2	1	1	1

Route Enumeration & Evaluation

Perception Factors:

- Waitfactors
- Boarding Penalties
- Runfactors

Route Evaluation

Perception Factors:

- XFERPEN * XFERFACTOR + XFERCONST
- Values of Time

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PT Skimming and Assignment: Elapsed Time

Skimming (times rounded to closest minute)	**PK**	**OP**
Route Enumeration	3 minutes	2 minutes
Route Evaluation and Skimming	11 minutes	10 minutes
Total	**14 minutes**	**12 minutes**

Running in parallel with CUBE Cluster, so around 14 minutes total

Assignment (times rounded to closest minute)	**AM**	**MD**	**PM**	**NT**
Route Enumeration	3 minutes	2 minutes	3 minutes	2 minutes
Route Evaluation and Loading	14 minutes	12 minutes	12 minutes	12 minutes
Total	**17 minutes**	**14 minutes**	**15 minutes**	**14 minutes**

Running in parallel with CUBE Cluster, so around 17 minutes total

Terminology: Estimation vs Calibration vs Validation

- **Estimation**: implies statistical analysis and testing
  - Finding functional forms
  - Finding significant parameters to be included in the model specification
  - Finding values of parameters making observed data more likely to be reproduced under the model specification
- **Calibration**: implies modeler expertise and refinement procedures
  - Implies assumption of some parameters from literature/experience
  - Choosing/adjusting parameter values to optimize Goodness of Fit measures
  - Can imply usage of additional adjustment factors/parameters
- **Validation**: implies checking what defined in estimation/calibration
  - Same reference year but different dataset (rates, different aggregation, data partition) or "Dynamic Validation" / Back-Casting using data from different periods
  - Still underlines the main concept of Goodness of Fit measures
  - Tests and quantifies the ability of the model to predict future scenarios

common dataset (Estimation, Calibration)

different dataset (Validation)

Calibration (run27_t2_2): Base Year 2019

Ridership and Goodness of Fit for groups of operators

OPERATORA	AGGROP	Observed	Model	% diff
1	WMATA bus	365,600	359,841	-2%
2	WMATA rail	655,953	613,034	-7%
3	MARC	40,700	31,082	-24%
4	VRE	19,300	14,326	-26%
5	ART	10,900	11,419	5%
6	DASH	14,300	9,596	-33%
7	Fairfax City Bu	2,000	3,391	70%
8	Fairfax Connect	27,800	51,187	84%
9	Loudoun Transit	6,000	6,949	16%
10	PRTC/Omniride	8,400	11,860	41%
11	RideOn	71,000	55,520	-22%
12	PG TheBus	10,000	9,332	-7%
13	RTA Central Mar	3,200	7,214	125%
14	Fredericksburg	1,000	2,392	139%
15	Calvert County	400	922	131%
16	Carroll County	500	680	36%
17	St Mary's STS	1,200	1,460	22%
18	MARTZ	400	140	-65%
-	***Total***	***1,238,653***	***1,190,345***	***-4%***

%RMSE = 18%
R^2 = 0.99

Calibration (run27_t2_2): Base Year 2019

Ridership and Goodness of Fit for groups of ART lines

ROUTE_ID	OPERDESCR	Observed	Model	% diff
41	ART	2,233	1,275	-43%
42	ART	1,127	1,067	-5%
43	ART	750	377	-50%
45	ART	1,250	904	-28%
51	ART	317	208	-34%
52	ART	315	337	7%
53	ART	162	584	260%
55	ART	1,653	2,542	54%
61	ART	117	56	-52%
62	ART	83	223	169%
72	ART	576	1,864	224%
74	ART	69	40	-42%
75	ART	602	529	-12%
77	ART	704	628	-11%
84	ART	239	151	-37%
87	ART	678	632	-7%
-	***Total***	***10,875***	***11,417***	**5%**

%RMSE =72%
R^2 = 0.50

Calibration (run27_t2_2): Base Year 2019

Ridership and Goodness of Fit for groups of DASH lines

ROUTE_ID	OPERDESCR	Observed	Model	% diff
AT1	DASH	1,500	1,108	-26%
AT2	DASH	1,450	1,779	23%
AT2X	DASH	120	266	122%
AT3	DASH	650	128	-80%
AT4	DASH	510	348	-32%
AT3-4	DASH	50	12	-76%
AT5	DASH	1,400	1,609	15%
AT6	DASH	800	601	-25%
AT7	DASH	600	135	-78%
AT8	DASH	2,600	2,500	-4%
AT9	DASH	510	677	33%
AT10	DASH	450	254	-44%
Trolley	DASH	1,900	54	-97%
-	***Total***	***12,540***	***9,471***	***-24%***
%RMSE =60% **R^2 = 0.55**				

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Calibration (run27_t2_2): Base Year 2019

Ridership and Goodness of Fit for groups of DASH lines

N	Metrorail Station	Observed	Model	% diff
8046	Van Dorn Street	2,265	2,685	19%
8047	Franconia-Springfield	5,172	7,951	54%
8048	Huntington	5,832	5,748	-1%
8049	Eisenhower Avenue	1,585	722	-54%
8050	King Street	5,679	5,034	-11%
8051	Braddock Road	3,826	2,982	-22%
8052	Reagan Washington National Airport	5,715	791	-86%
8053	Crystal City	10,847	6,904	-36%
8054	Pentagon City	12,133	3,713	-69%
8055	Pentagon	13,785	16,159	17%
8056	Arlington Cemetery	1,086	16	-99%
8057	Vienna	8,686	9,286	7%
8058	Dunn Loring	3,720	2,627	-29%
8059	West Falls Church	2,463	3,107	26%
8060	East Falls Church	3,813	6,021	58%
8061	Ballston	9,232	7,157	-22%
8062	Virginia Square-GMU	3,793	3,658	-4%
8063	Clarendon	4,478	4,186	-7%
8064	Court House	6,349	6,331	0%
8065	Rosslyn	13,059	10,033	-23%
8087	McLean	2,081	3,871	86%
8088	Tysons Corner	3,507	2,443	-30%
8089	Spring Hill	1,139	1,066	-6%
8090	Greensboro	1,415	1,166	-18%
8091	Wiehle	7,650	9,162	20%
-	***Total***	***139,310***	***122,819***	***-12%***

%RMSE =45%

R^2 = 0.62

Calibration (run27_t2_2): Base Year 2019

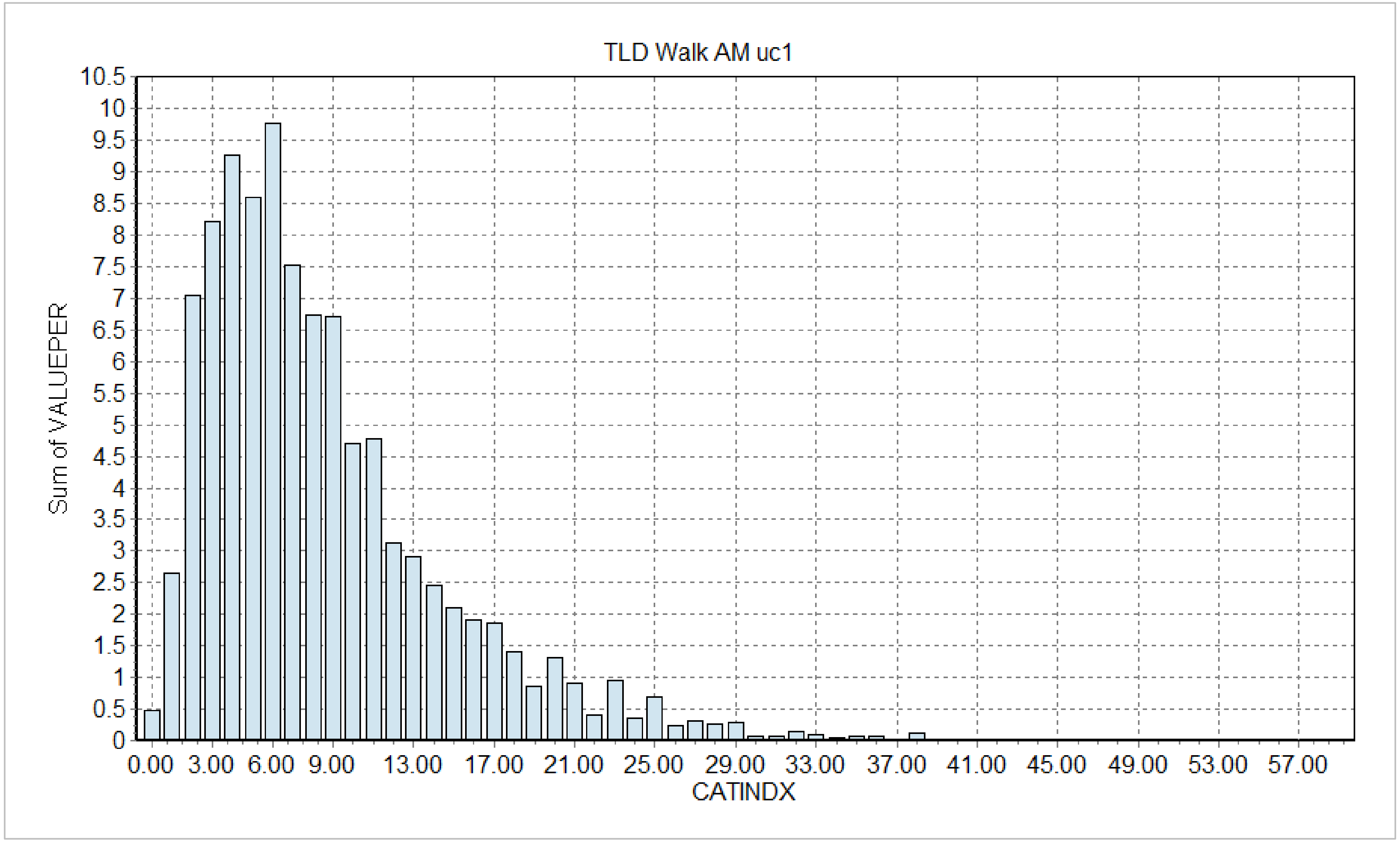
Volumes crossing Potomac River using the Metrorail sub-mode

Period	Observed	Model	% diff
AM	72,148	47,189	-35%
MD	31,194	20,495	-34%
PM	77,214	43,250	-44%
NT	18,781	21,874	16%
Daily	***199,337***	***132,808***	***-33%***

Daily percentage for the number of transfers (average)

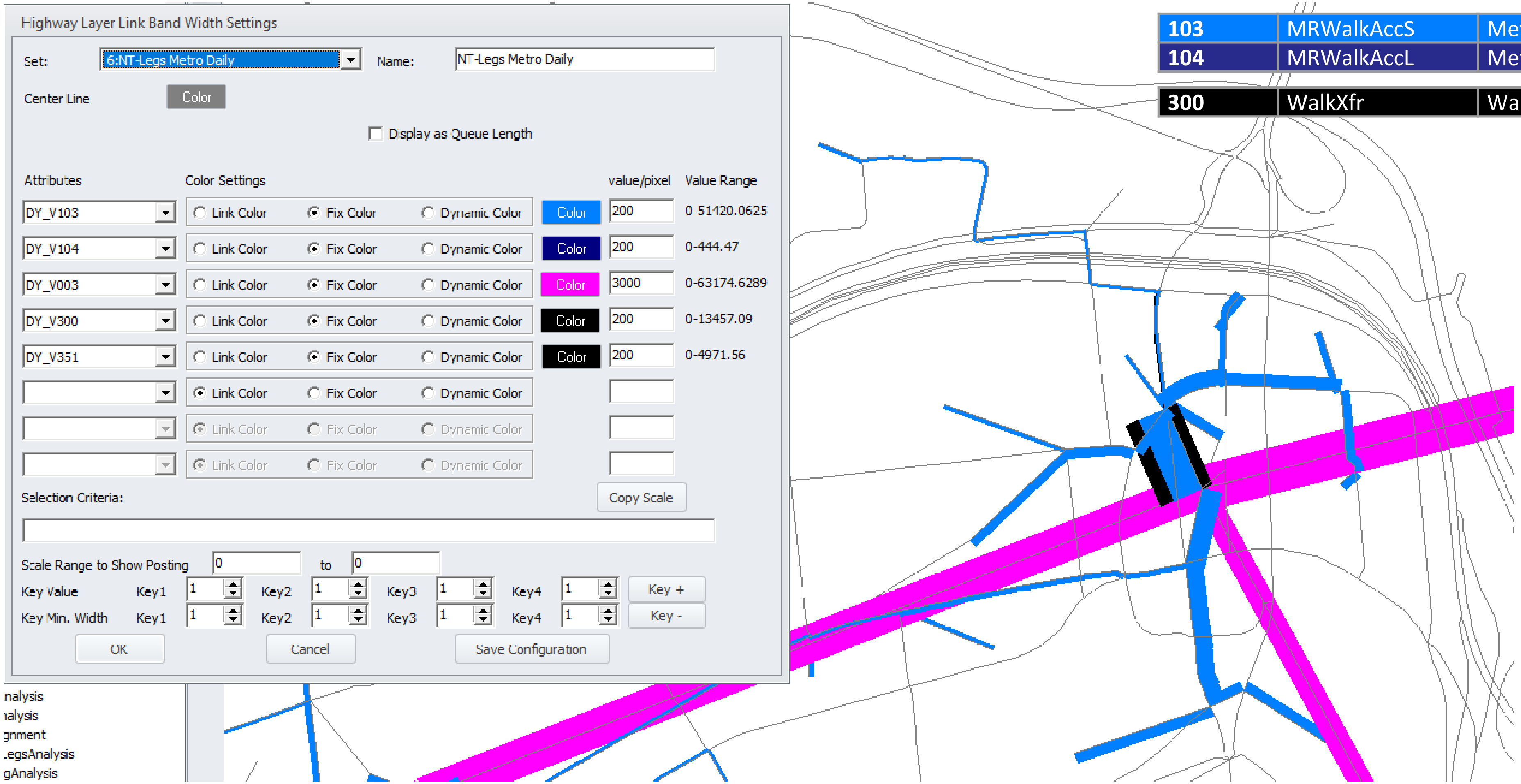
XFERS	Target	Model
0	65.0%	63.5%
1	30.0%	31.2%
2	4.5%	5.0%
3+	0.5%	0.4%

Frequency TLD of access walk time for uc1 (AM)



CATINDX = 1 minute interval

Metrorail Rosslyn Daily Boardings



Note: Metrorail on-board passenger volumes with different scale

 |

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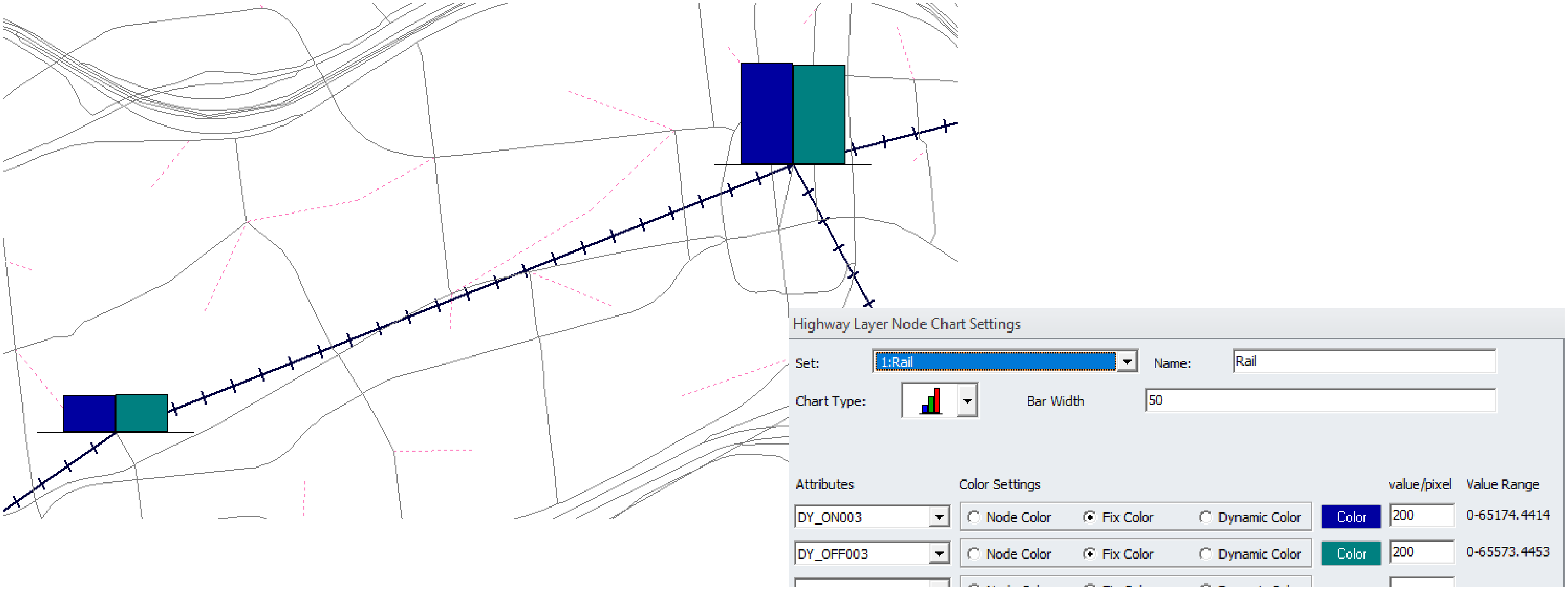
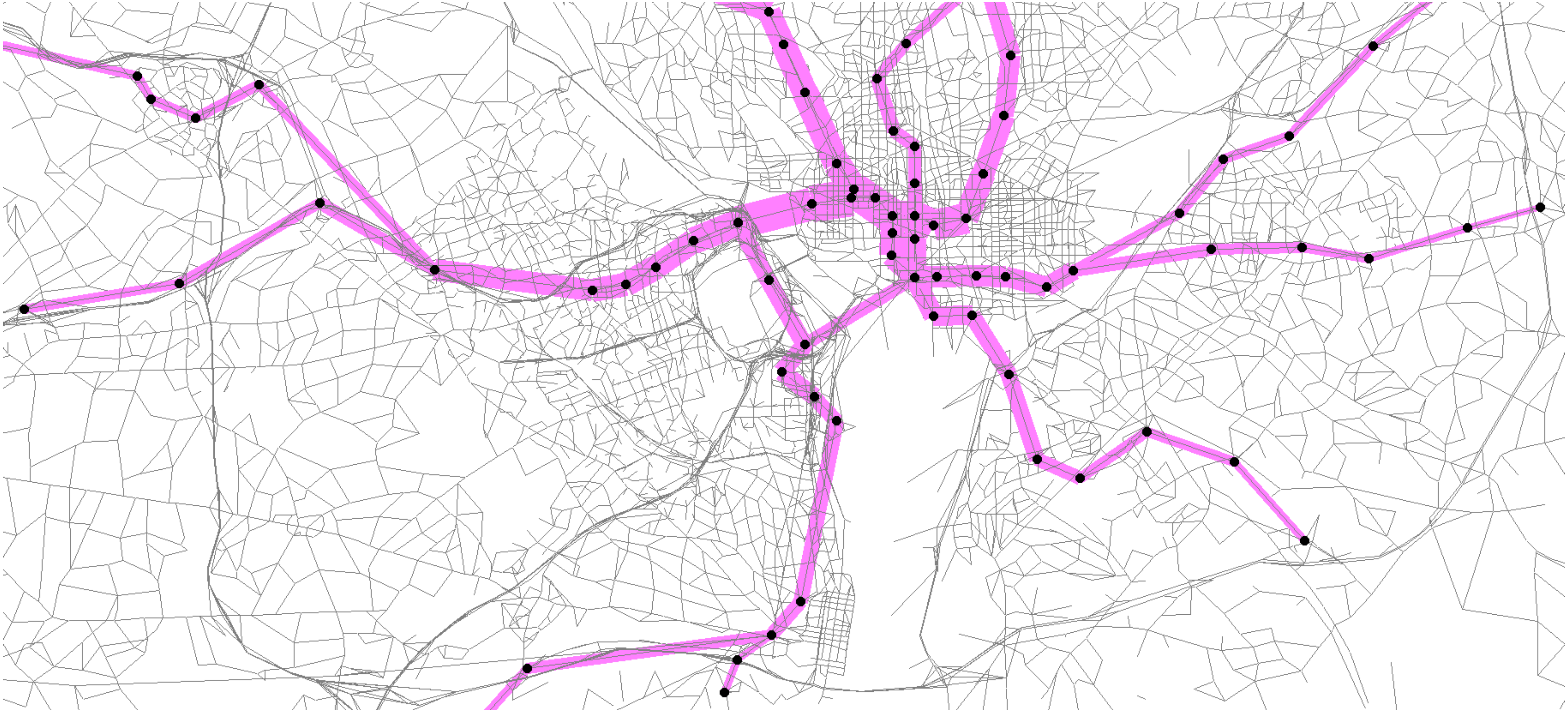
Metrorail Court House and Rosslyn Daily On Vs Off

N	Metrorail Station	Observed	Model
8064	Court House	6,349	6,331
8065	Rosslyn	13,059	10,033



Metrorail Rider Bandwidth Plot



Potential Future Improvements

- Improvement of PT Lines coding:
  - Phase 2 files' schema and ART line coding
  - time periods' frequencies (PM, NT)
- Phase 2 Further analysis of the PT crowding external/auxiliary process and inclusion in the tour-based model feedback-loop
- Further analysis and inclusion of the walk-index calculation for NT-Legs generation
- Future refinement of the model can investigate the inclusion of additional user classes based on:
  - Type of active mode, e.g., bike, e-scooters, etc.
  - Income category
- Phase 2 Volumes crossing Potomac River using Metrorail sub-mode show an underestimation, this could be part of future analysis and refinement
- Phase 2 Analysis for stations showing major inconsistencies between observed vs modelled ridership has been undertaken (document "PT_Arlington_MetroRail_Station_Analysis_v08.01.docx") for future reference for model refinement

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Note on PT Crowding Auxiliary Process

PT crowding could be affecting the following levels of decision, from lower to higher level (note: other choice behaviors exist but are not mentioned below for simplicity):

- Line Choice behaviours
- Route Choice behaviours
- PT Sub-Mode Choice behaviours
- Time-of-Day Choice / Peak-Spreading behaviours
- Mode Choice behaviours
- Destination Choice behaviours

External / auxiliary process

Note on PT Crowding Auxiliary Process

- Avoid complexity and increased runtime of iterative PT crowding assignment
- Overcome the needs for more detailed PT crowding data
- Still being able to evaluate effects of the system capacity within the overall model.

PUBLIC TRANSPORT
Route Evaluation and Loading
(No Crowding considered)

LINKO[1]

STEP 1. A-B link sequence by Line, with Volumes and Capacities
↓
STEP 2. "Stop-to-Stop Segments" sequence by Line, with Volumes and Capacities → UTILIZATION

STIO2STOPO[1]

STEP 3. "Board-Alight Stop-to-Stop Leg" by OD, with demand proportions

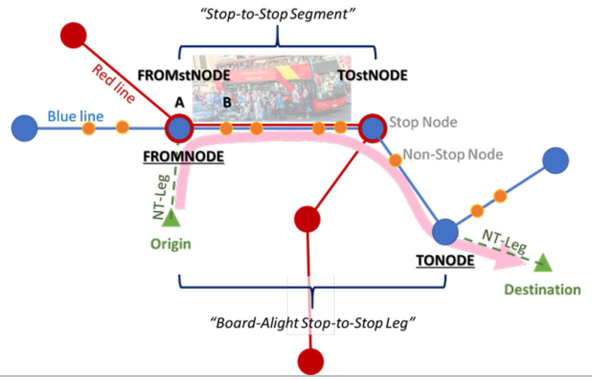
STEP 4. Stop-to-Stop Segments by OD pair and crowding level

STEP 6. "Potential Paths" of "Stop-to-Stop Segments" for each "Board-Alight Stop-to-Stop Leg" by OD, with ACCUMULATED Volumes, Capacities, Utilizations, and "potential" demand proportions

STEP 7. (Aggregation) Utilization at OD pair level accumulating Volumes and Capacities only for "Stop-to-Stop Segments" that are overcrowded that are "potentially crossed"

Note: possible to be refined by using different weights by PT sub-mode

Calculation of the **Equivalent In-Vehicle Travel Time due to Crowding at OD pair level**



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