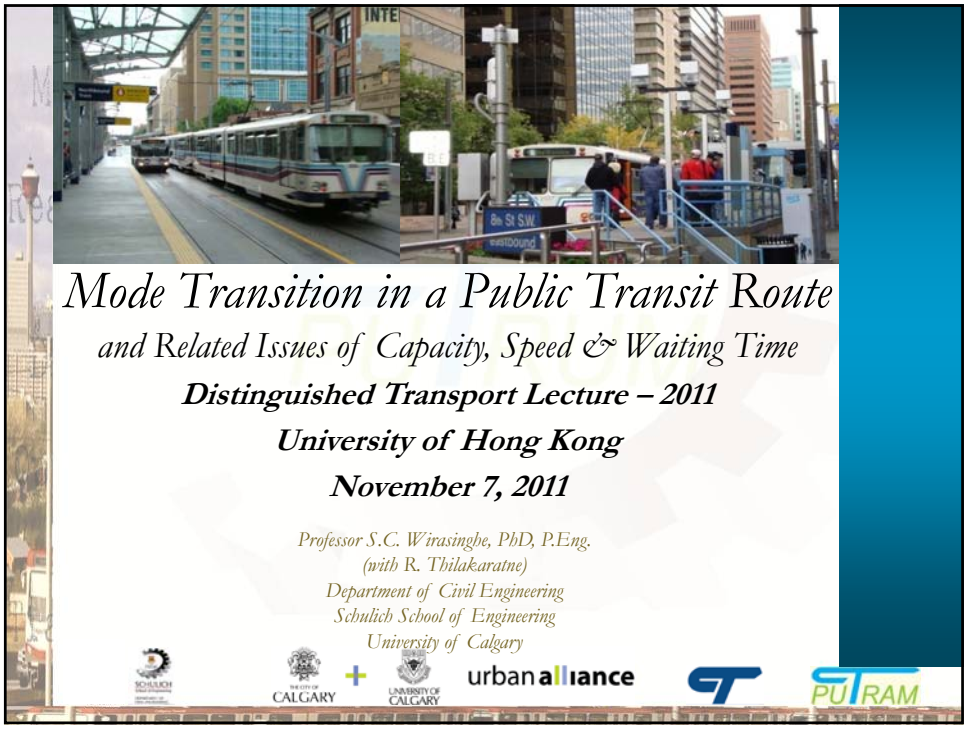


Mode Transition in a Public Transit Route

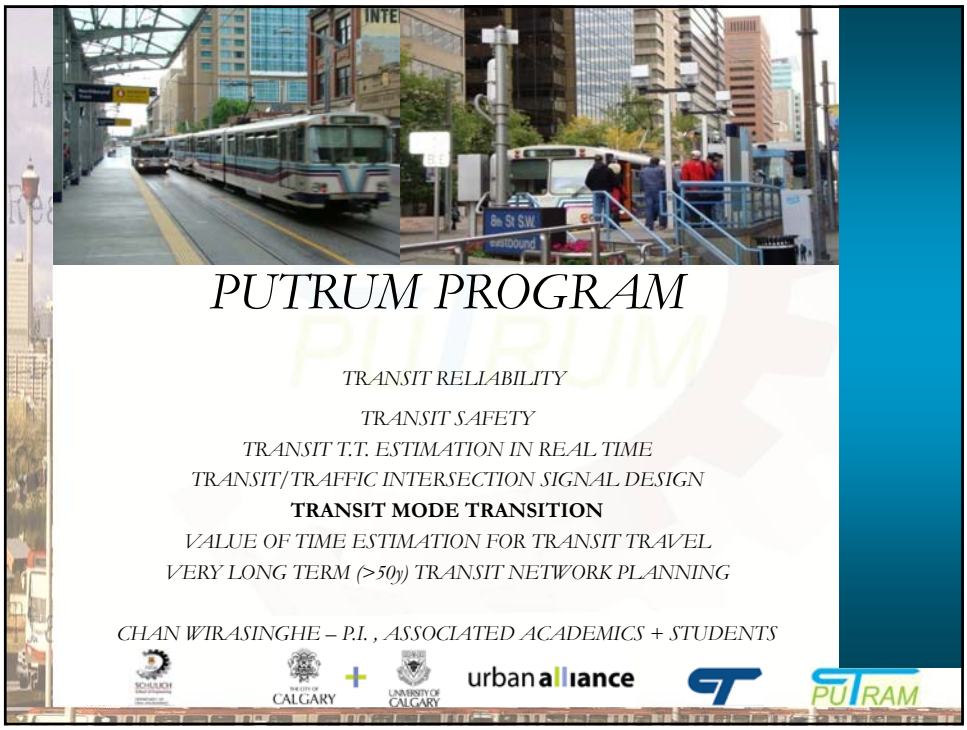
and Related Issues of Capacity, Speed & Waiting Time

Distinguished Transport Lecture – 2011

University of Hong Kong

November 7, 2011

Professor S.C. Wirasinghe, PhD, P.Eng.
(with R. Thilakaratne)
Department of Civil Engineering
Schulich School of Engineering
University of Calgary



PUTRUM PROGRAM

TRANSIT RELIABILITY

TRANSIT SAFETY

TRANSIT T.T. ESTIMATION IN REAL TIME

TRANSIT/TRAFFIC INTERSECTION SIGNAL DESIGN

TRANSIT MODE TRANSITION

VALUE OF TIME ESTIMATION FOR TRANSIT TRAVEL

VERY LONG TERM (>50y) TRANSIT NETWORK PLANNING

CHAN WIRASINGHE – P.I. , ASSOCIATED ACADEMICS + STUDENTS

Introduction

- *As transit corridors evolve through land use, socio-economic and technological changes, new modes must be introduced to cater to the new demands for travel.*
- *Planning for mode transition must occur well in advance (in some cases, up to decades).*
- *Study of mode transition requires knowledge of capacity and speed as well as other modal characteristics.*
- *Each mode (and in some cases mode mixes) must be optimized in terms of the functional design.*

Typical Characteristics of Public Transit Modes

Transit Mode	Typical Features
Regular Bus	▪ All stop-run based on passenger demand ▪ Mixed traffic ▪ Standard or articulated bus ▪ Scheduled or high frequency service ▪ Lower fares ▪ On-board fare collection ▪ Low operating speed
Express Bus	▪ Circulate in a zone and run non-stop to a major destination ▪ Mixed traffic ▪ Standard or articulated bus ▪ Scheduled headway service ▪ Higher prices possible compared to regular buses ▪ On-board fare collection ▪ High Operating Speed ▪ Peak hour operations ▪ Long spacings between stops (primarily long trips)

Transit Mode	*Typical Features*
Bus Rapid Transit (BRT)	▪ Limited-stop run through selected origins and destinations ▪ Mixed traffic ▪ Articulated buses or Specialized buses ▪ Scheduled service ▪ Higher fares ▪ Fair collection using ICT (Intelligent Communication Technology) ▪ Medium operating speed ▪ Intelligent Transportation Systems (ITS) - Transit (Signal) priority
Busway	▪ All stop with longer stop (station) spacings ▪ Dedicated running ways ▪ Standard or (bi-/tri-) articulated buses or Specialized buses ▪ Scheduled or fixed headway service ▪ Higher fares ▪ Fair collection using ICT ▪ Higher Operating Speed ▪ Easy-to-board (low-floor) buses for rapid passenger exchange ▪ Multi-channel doors (multiple door boarding) ▪ Simultaneous berthing for two or more vehicles/ Station bypassing ▪ Real-time passenger information systems

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Transit Mode	*Typical Features*
Light Rail Transit (LRT)	▪ All stop at all stations ▪ Mostly on separated Right Of Way ▪ Electrically powered articulated, multi-unit light trains ▪ Fixed headway service ▪ Higher fares ▪ Fair collection using ICT ▪ High passenger attraction and line capacity ▪ High operating speeds and comfortable ride quality ▪ Vertical access to elevated/ underground stations (Elevator/ Escalator/ Steps) ▪ Multi-channel doors (multiple door boarding) ▪ High investment cost (vehicle, infrastructure and line costs)
Metro	▪ All stop at all stations ▪ Separated Right Of Way ▪ Electrically powered articulated, multi-unit trains ▪ High frequency service ▪ Higher fares ▪ Fair collection using ICT ▪Stronger passenger attraction and line capacity ▪Higher operating speed relative to other transit modes ▪Fully automatic (automatic signalling or train control) ▪Longer trains with multi-channel doors (multiple door boarding) ▪Very High investment cost (vehicle, infrastructure and line costs)

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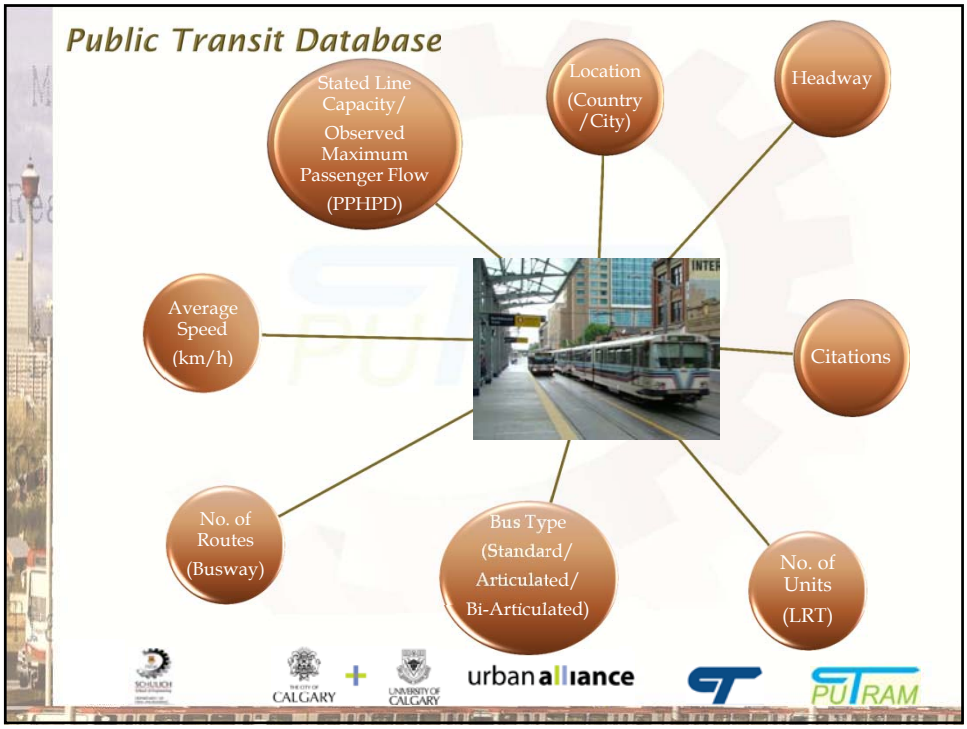
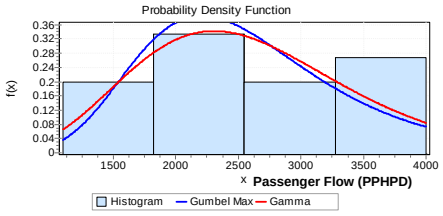
Public Transit Database



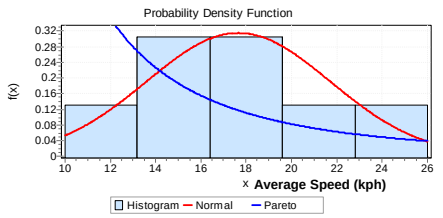
Regular Bus

Maximum Flow/Capacity Data



		χ^2
Best Fit	Gumbel Max	(9.87×10^{-6})
Another Fit	Gamma	(2.25×10^{-3})
Properties	Mean	2691.5
	St. Dev.	1085.0
Level of Confidence		99%
		99%

Speed Data



		χ^2
Best Fit	Pareto	(1.11×10^{-2})
Another Fit	Normal	(0.1180)
Properties	Mean	17.7
	St. Dev.	6.0
Level of Confidence		99%
		99%

The Best and Another Close Fits

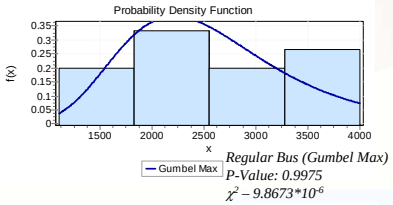
Observed Route/Line Capacity Data

Transit Mode	The Best Fit (P-Value)	The Most Familiar Close Fit (P-Value)
Regular Bus	Gumbel Max (0.9975)	Gamma (0.4095)
Express Bus	Weibull (0.7061)	Gamma (0.6515)
Bus Rapid Transit	Weibull-3P (0.9926)	Normal (0.9413)
Busway	Cauchy (0.8497)	Gamma (0.7948)
Light Rail Transit	Burr (0.9744)	Beta (0.9002)
Metro	Log-Pearson3 (0.9973)	Beta (0.7000)

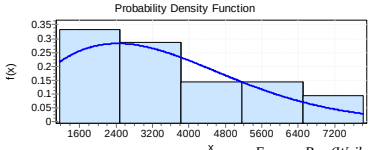
Average Speed Data

Transit Mode	The Best Fit (P-Value)	The Most Familiar Close Fit (P-Value)
Regular Bus	Pareto (0.9159)	Normal (0.8688)
Express Bus	Log-Logistic (0.6726)	Beta (0.5635)
Bus Rapid Transit	Burr-4P (0.9921)	Beta (0.8391)
Busway	Gen. Logistic (0.7737)	Gamma (0.0754)
Light Rail Transit	Frechet (0.7719)	Beta (0.4455)
Metro	Wakeby (0.9534)	Chi-Squared (0.4861)

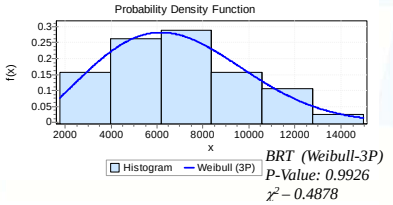
The Best Fits for Capacity Data



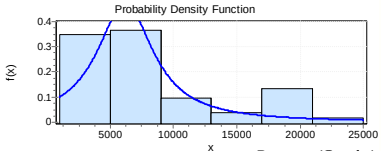
Regular Bus (Gumbel Max)
P-Value: 0.9975
$\chi^2 - 9.8673*10^{-6}$



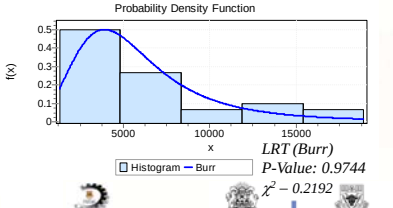
Express Bus (Weibull)
P-Value: 0.7061
χ^2 - 0.6961



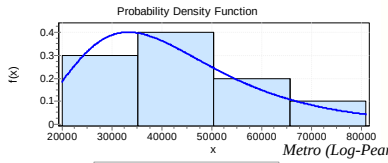
BRT (Weibull-3P)
P-Value: 0.9926
$\chi^2 - 0.4878$



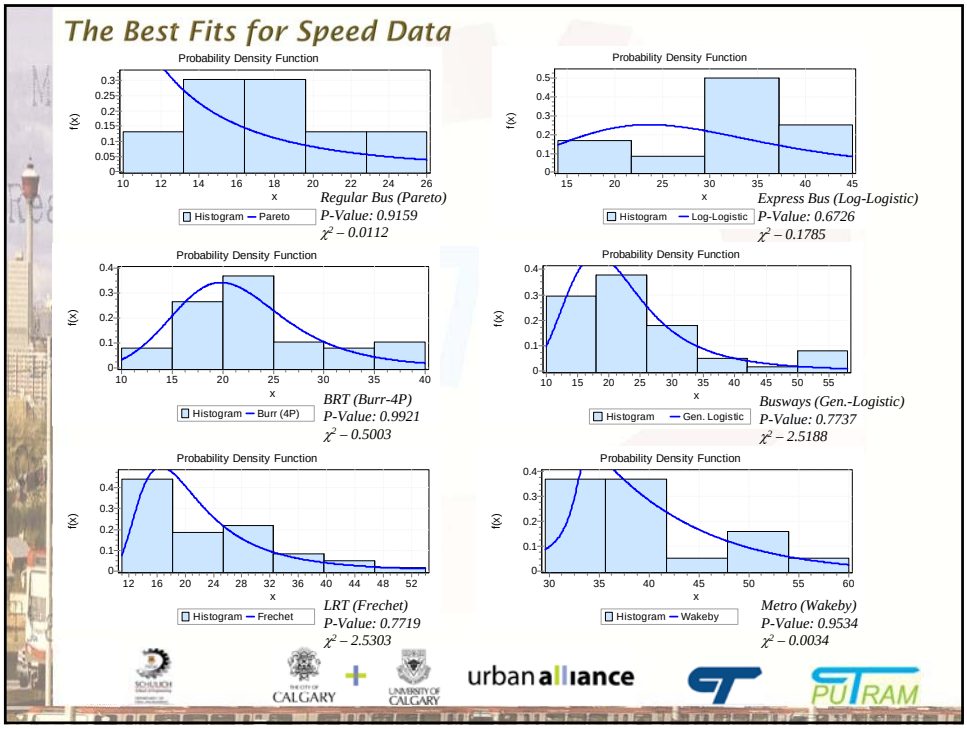
Busways (Cauchy)
P-Value: 0.8497
$\chi^2 - 1.3684$



LRT (Burr)
P-Value: 0.9744
$\chi^2 - 0.2192$



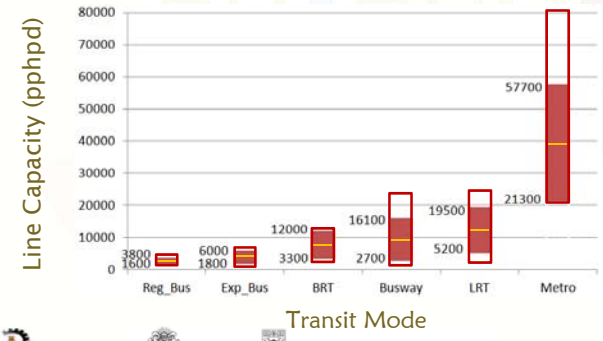
Metro (Log-Pearson3)
P-Value: 0.9973
$\chi^2 - 1.1633x10^{-5}$



Overall Capacity Analysis

Transit Mode	μ	σ	CV	90% Confidence Interval
Regular Bus	2692	1085	0.40	1400 - 4300
Express Bus	3914	2080	0.53	700 - 7000
BRT	7669	4359	0.57	2400 - 12300
Busway	9436	6694	0.71	1000 - 23300
LRT	12371	7163	0.58	1700 - 15900
Metro	39478	18191	0.46	20200 - 80400

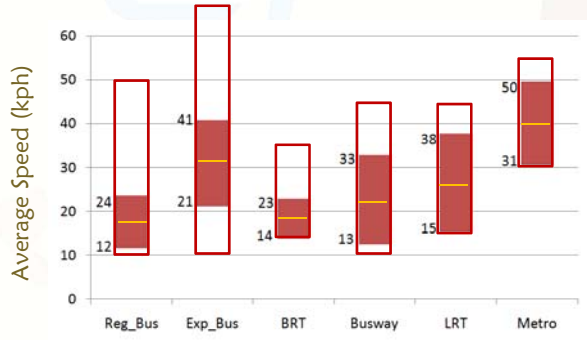
Capacity Distribution : Range of Mean ± SD, 90% CI



Overall Speed Analysis

Transit Mode	μ	σ	CV	90% Confidence Interval
Regular Bus	17.7	6.0	0.34	10 - 50
Express Bus	31.0	9.8	0.32	10 - 70
BRT	18.3	4.5	0.24	15 - 35
Busway	22.7	10.2	0.45	10 - 45
LRT	26.5	11.3	0.43	15 - 45
Metro	40.1	9.5	0.24	30 - 55

Speed Distribution : Range of Mean ± SD



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Uncertainties (Express Bus)

Common Uncertainties:

Route Length, Fare Collection Method, Signal Priority

Express Bus Capacity Data Subcategorized under Vehicle Type

Route Capacity (pphpd)			Vehicle Type	Route Capacity (pphpd per route)		
Mean	SD	Sample Size		Mean	SD	Sample Size
3914	2080	21	Standard	1780	580	12
			Articulated	5473	624	9

Right of Way	Route Capacity (pphpd per route)		
	Mean	SD	Sample Size
Arterials	2863	1742	16
Highways	5666	2075	5

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Uncertainties (Busways)

Busway Capacity Data Subcategorized (Vehicle Type, Capacity Per Route)*

Vehicle Type	Corridor Capacity (pphpd)			Route Capacity (pphpd per route)		
	Mean	SD	Sample Size	Mean	SD	Sample Size
Standard	6150	4337	18	364	171	7
Standard /Articulated	7163 6785 6217	4311 3759 2922	12	446	217	6
Articulated			8	1874	1104	3
Double articulated	8251	3334	4	4483	1946	4

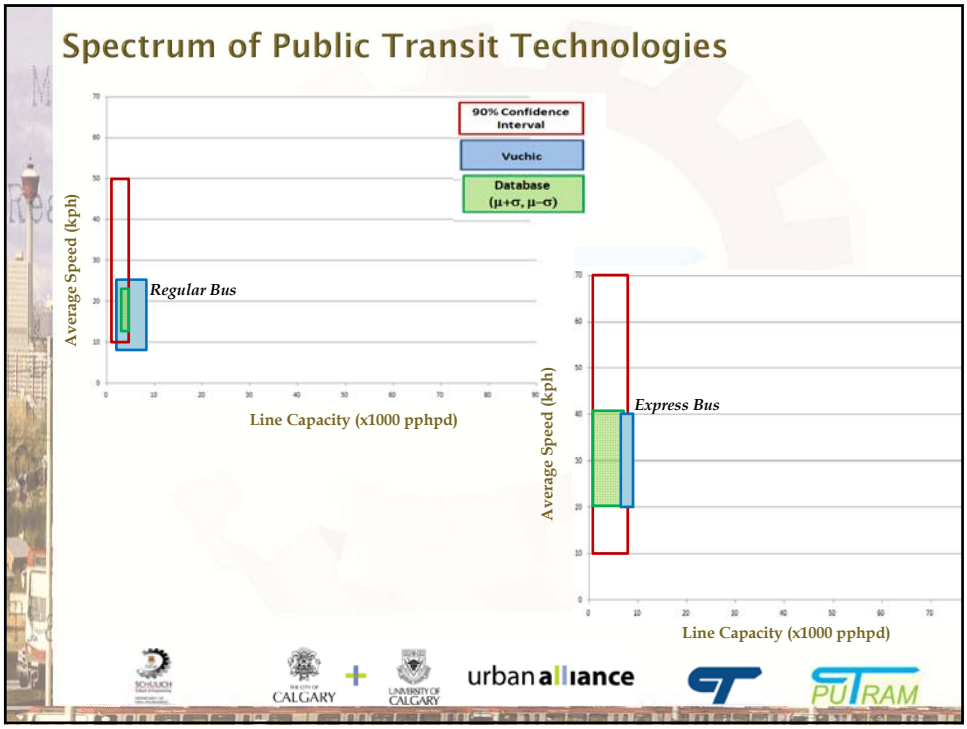
Uncertainties (LRT)

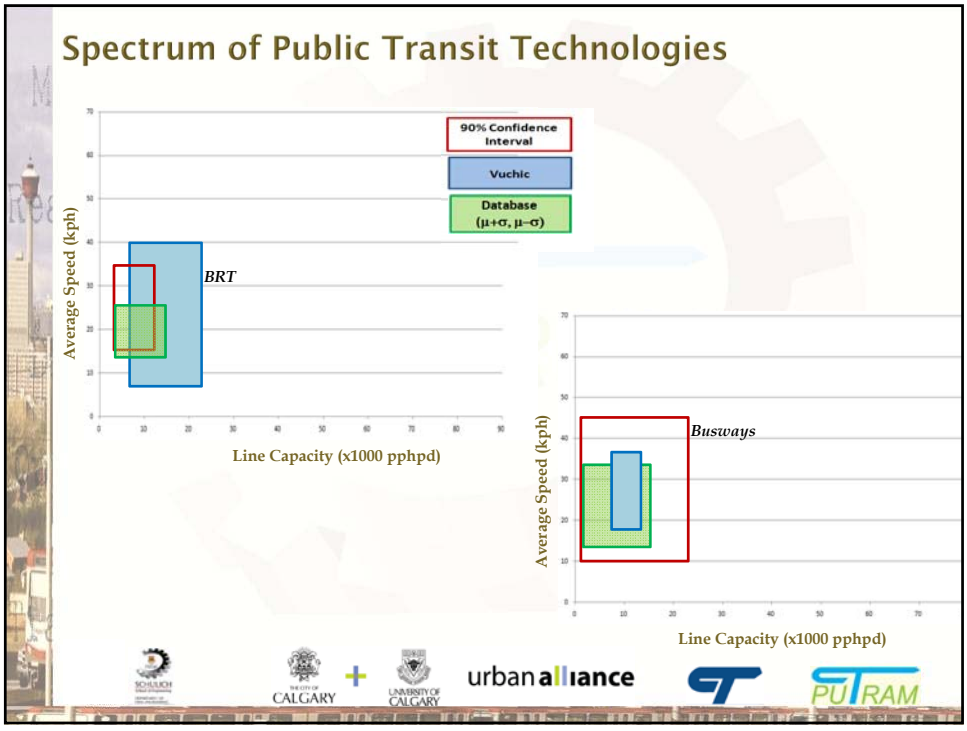
LRT Capacity Data Subcategorized under Number of Vehicles

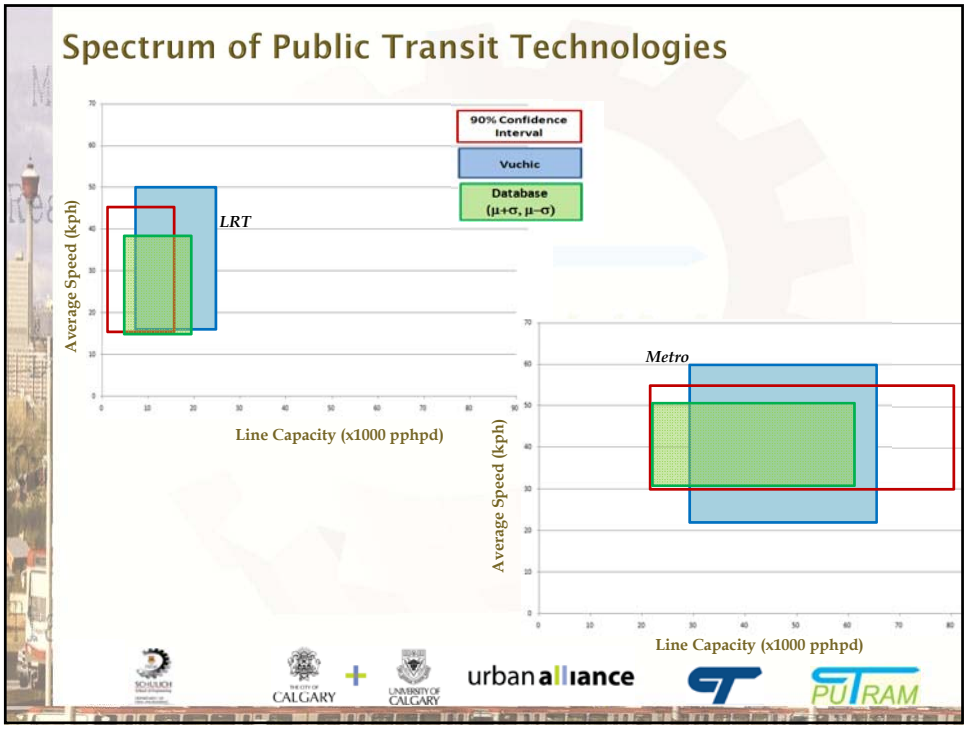
Line Capacity (pphpd)			Number of Cars per Train	Line Capacity (pphpd)		
Mean	SD	Sample Size		Mean	SD	Sample Size
5788	4431	22	1	3830	1448	4
			1,2	5596	4495	17
			2	6139	5006	13
			3	6300	5351	4
			3,4	6440	4903	5
			4	7000	-	1

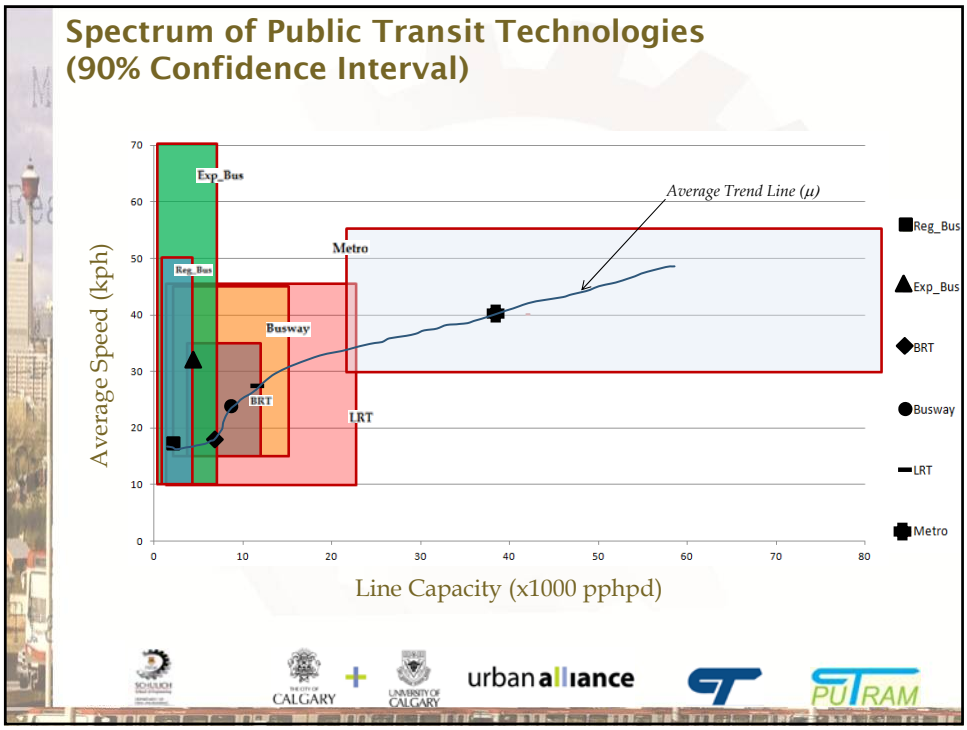
LRT Speed & Capacity Data Subcategorized under Right Of Way (ROW)

ROW	Average Speed (kph)			Line Capacity (pphpd)		
	Mean	SD	Sample Size	Mean	SD	Sample Size
Separated	50	4.18	7	23520	4425.86	4
Shared	24	8.32	78	11779	6888.31	64
Mix of both	26	11.00	85	12470	7296.49	68









Order of Performance: (Ranking Order)

Regular Bus

Express Bus

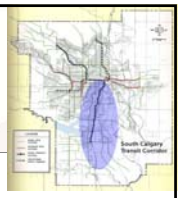
BRT

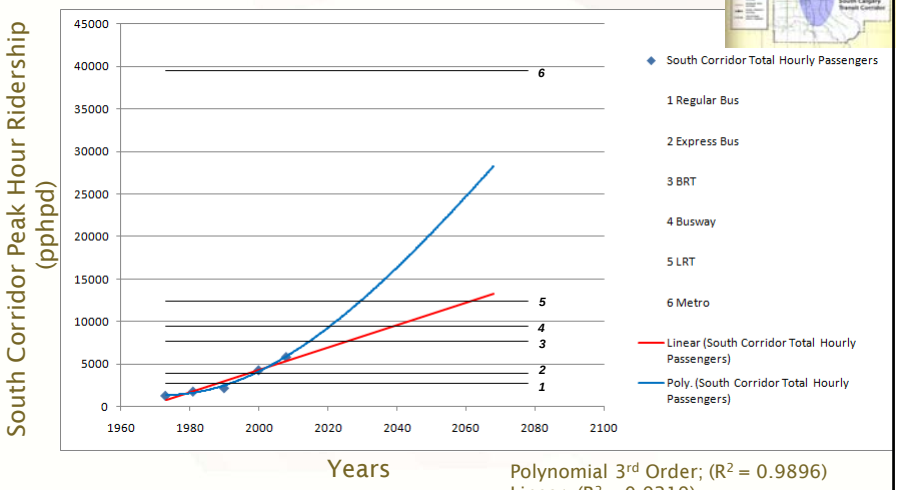
Busway

LRT

Metro

Application: South (Macleod Trail) Corridor, Calgary





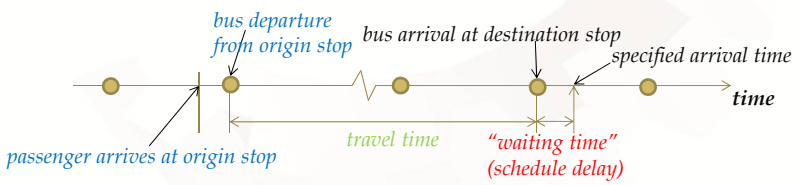
Polynomial 3rd Order; (R^2 = 0.9896)
Linear; (R^2 = 0.9219)

"Waiting" Time for a Passenger due to Schedule

- *Are buses "scheduled"?*
- *Does the passenger have a specific "arrival" time at the destination stop?*
- *Does the passenger have a specific "departure" time at the origin stop?*
- *Is the bus schedule available to passengers in real time?*
- *Where will the waiting take place?*
- *Does the passenger, if he/she is travelling to work, have flexible work hours?*
- *Additional "waits/delays" are caused by reliability issues.*

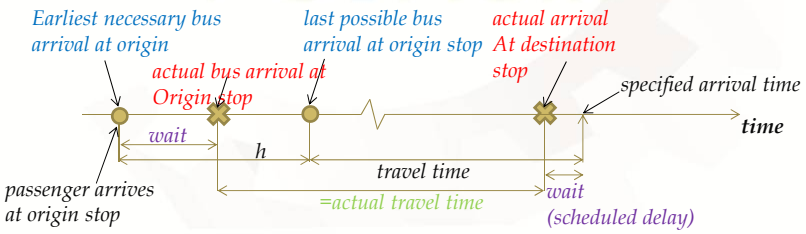
Mean Passenger Waiting Time when the Schedule is known

	Specific departure time	*No specific departure time*
Specific arrival time	*Not possible*	$\frac{1}{2}H$ *(work)*
No specific arrival time	$\frac{1}{2}H$ *(stop; home)*	*zero*



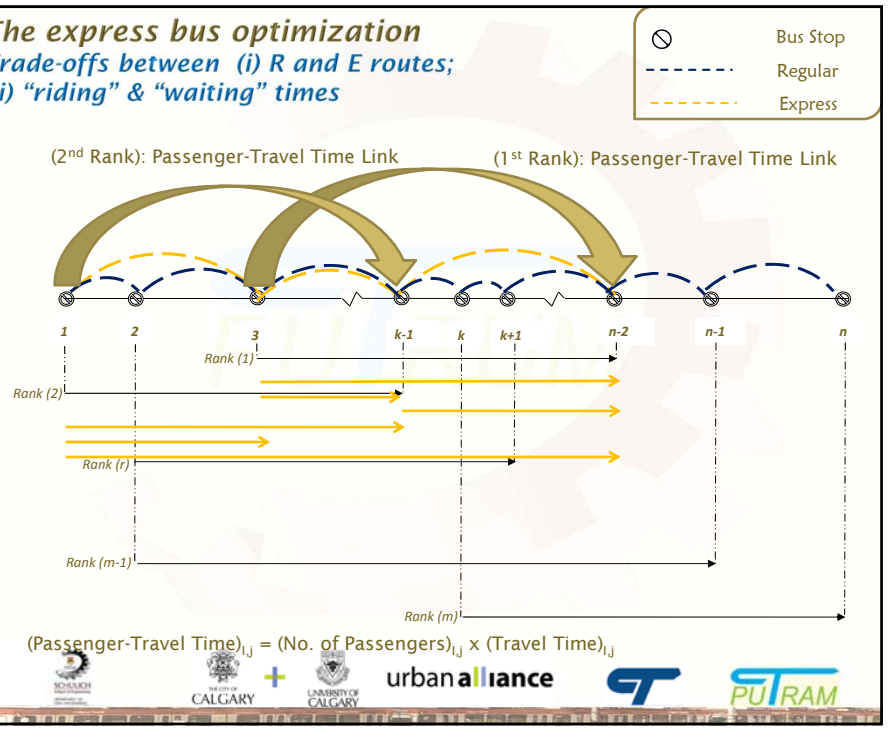
Mean Passenger Waiting Time when the Schedule is unknown, but "h" is known

	Specific departure time	No specific departure time
Specific arrival time	Not possible	H (stop; work)
No specific arrival time	$\frac{1}{2}H$ (stop)	$\frac{1}{2}H$ (stop)



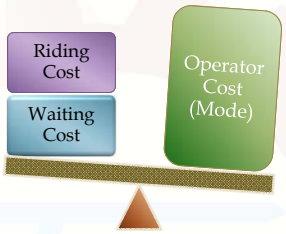
The express bus optimization

Trade-offs between (i) R and E routes; (ii) "riding" & "waiting" times



$(\text{Passenger-Travel Time})_{i,j} = (\text{No. of Passengers})_{i,j} \times (\text{Travel Time})_{i,j}$

Objective Function:



Passenger Cost:
Waiting Cost & Riding Cost (Regular & Express Bus Passengers)

Operator cost :
Dispatch of (regular and express) buses inclusive of crew wages, operating costs, and the cost of owning the bus.

Analytical Model:

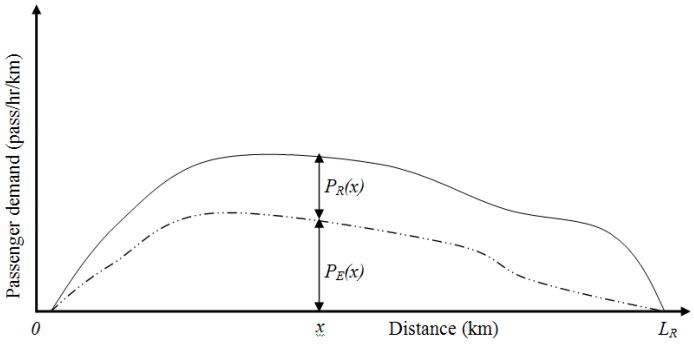


Figure 5-1: Demand Density Functions for Regular and Express Bus Services

$$P_R = \int_0^{L_R} P_R(x)dx$$

$$P_E = \int_0^{L_R} P_E(x)dx$$

$P_R + P_E = P_T$, where P_T is the total passenger demand.

Total Passenger Travel Time Cost $= \frac{\gamma_R P_R}{V_R}\bar{L}_R + \frac{\gamma_R P_E}{V_R}\bar{L}_E$ (for scheduled-regular bus system) -**E1**

$= \frac{\gamma_R P_R}{V_R}\bar{L}_R + \frac{\gamma_R P_E}{V_E}\bar{L}_E$ (for the combined service) – **E2**

where $\bar{L}_E$ and $\bar{L}_R$ are the average passenger-distances for the local and express bus demands respectively, given by

$$\bar{L}_R = \frac{\int_0^{L_R} m_R(x)dx}{P_R} \quad \text{and} \quad \bar{L}_E = \frac{\int_0^{L_R} m_E(x)dx}{P_E}$$

Passenger Waiting Time Cost $= \gamma_W \frac{h_R}{2}(P_R + P_E)$ (for scheduled-regular bus system) – **E3**

$= \gamma_W \frac{h_R'}{2}P_R + \gamma_W \frac{h_E'}{2}P_E$ (for the combined service) - **E4**

Dispatching Cost $= \frac{\gamma_D L_R}{h_R}$ (for scheduled-regular bus system) – **E5**

$= \frac{\gamma_D L_R}{h^N{}_R} + \frac{\gamma_E L_E}{h_E}$ (for the combined service) – **E6**

The total cost (passenger time costs and dispatching cost) for the regular bus system, $Z^G{}_R$

$$Z^G{}_R = \left\{\frac{\gamma_R}{V_R}(P_E\bar{L}_E + P_R\bar{L}_R)\right\} + \gamma_W\frac{h_R}{2}(P_R + P_E) + \frac{\gamma_D L_R}{h_R} \quad \textbf{-E7}$$

The total cost for the combined regular/express bus system, $Z^G{}_T$

$$Z^G{}_T = \left\{\gamma_R\left(\frac{P_R}{V_R}\bar{L}_R + \frac{P_E}{V_E}\bar{L}_E\right)\right\} + \frac{\gamma_W}{2}\left(h^N{}_R P_R + h_E P_E\right) + \frac{\gamma_D L_R}{h^N{}_R} + \frac{\gamma_E L_E}{h_E} \quad \textbf{-E8}$$

Optimize headways on regular route, and the express route, by minimizing the respective sum of passenger waiting time cost and operator cost ***(****differentiating the* ***Eqns. E7*** *and* ***E8*** *with respect to their headways and setting to zero****).***

Substituting the optimized headways back to the Eqns. E7 and E8, the minimum total cost functions $Z^{*G}{}_R$, $Z^{*G}{}_T$ *can be obtained*

The combined limited-stop (express) /local operation can be worthwhile in transit corridor if

$$\boldsymbol{Z^{*G}{}_R > Z^{*G}{}_T}$$

$$\left(2\gamma_D\gamma_W L_R P_R\right)^{1/2}\left(1+\frac{P_E}{2P_R}\right) + \left\{\frac{\gamma_R}{V_R}(P_E\bar{L}_E + P_R\bar{L}_R)\right\} > \left(2\gamma_D\gamma_W L_R P_R\right)^{1/2} + \left(2\gamma_D\gamma_W L_E P_E\right)^{1/2} + \frac{\gamma_R P_R\bar{L}_R}{V_R} + \frac{\gamma_R P_E\bar{L}_E}{V_E}$$

The combined operation is optimal when;

$$\frac{\gamma_R}{(2\gamma_w)^{1/2}}\left\{\frac{1}{V_R}-\frac{1}{V_E}\right\} > \frac{1}{\bar{L}_E}\left\{\left(\frac{\gamma_E L_E}{P_E}\right)^{1/2} - \frac{1}{2}\left(\frac{\gamma_D L_R}{P_R}\right)^{1/2}\right\}$$

Where,

- γ_R – Value of Riding Time per passenger per hour
- γ_W – Value of Waiting Time per passenger per hour
- γ_D – Cost of Regular Bus Operation per hour
- γ_E – Cost of Express Bus Operation per hour
- V_R – Average speed of Regular Bus Service
- V_E – Average speed of Limited-stop/Express Bus Service
- L_R – Length of the Corridor (Regular Bus Service)
- L_E – Length of the Route for the Limited-stop/Express Bus Service
- $\bar{L}_E$ – Average Trip Length of Limited-stop/Express Bus Passengers
- P_R – Passenger Demand for Regular Bus Service
- P_E – Passenger Demand for Limited-stop/Express Bus Service

If regular and express buses are identical ,($\gamma_E = \gamma_D$)

$$\frac{\gamma_R}{(2\gamma_D\gamma_w)^{1/2}}\left\{\frac{1}{V_R}-\frac{1}{V_E}\right\} > \frac{1}{\bar{L}_E}\left\{\left(\frac{L_E}{P_E}\right)^{1/2} - \frac{1}{2}\left(\frac{L_R}{P_R}\right)^{1/2}\right\}$$

The above condition is always true if,

$$\left(\frac{P_E}{L_E}\right) > 4\left(\frac{P_R}{L_R}\right)$$

"The demand per unit length for the express route is greater than four times the demand per unit length for the local route."

Questioner Form

Calgary Transit PUTRAM

In partnership with urbanalliance

ROUTE 1 TRANSIT PASSENGER SURVEY

This survey is a partnership between Calgary Transit and the University of Calgary. To better understand and apply principles of urban planning, we request your assistance. Please complete the four questions on this survey and return it to the survey box near the front of the bus. Your answers are important to us and your individual responses will be held in strict confidence.

Q1 Please indicate where you boarded this bus. Write down either the bus stop number OR closest intersection.

Q2 Please indicate where you get off this bus. Write down either the bus stop number OR closest intersection.

Q3 Please circle the hour in which you boarded this bus.

○ 6am-7am ○ 7am-8am ○ 8am-9am ○ Other time

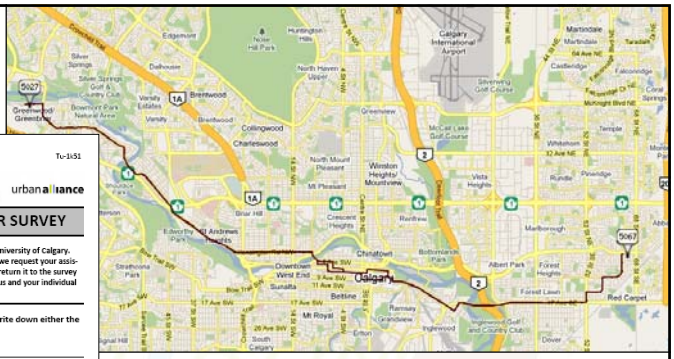
Q4 Please indicate your trip purpose. Check all that apply.

○ Work ○ School ○ Recreation
○ Shopping ○ Social ○ Other

For further information on this survey or if you have an questions, please contact either the University of Calgary contact at 403-220-5821 or at passengersurvey@gmail.com or Calgary Transit Customer Service at 403-262-1000.

Thank you for completing this survey. Please drop it into the survey box near the front of the bus by the operator.

The personal information on this form is collected under the authority of Section 33(c) of the Freedom of Information and Protection of Privacy Act. This information will be used for the purpose of understanding rider travel choices on the route 1 for a study being done at the University of Calgary. If you require further information, please contact Calgary Transit at 403-262-1000.



The alignment of the bus route 1 (Forest Lawn /Bowness)

232 Passengers

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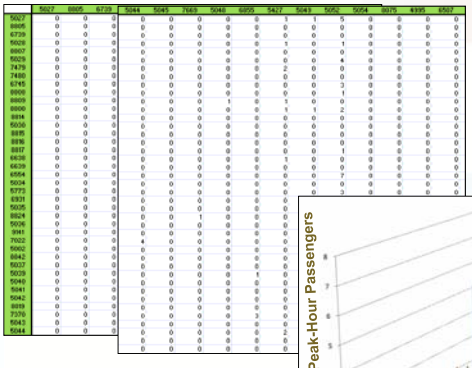
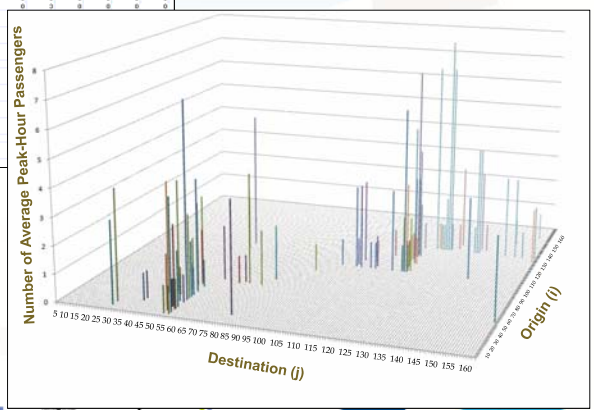
(O-D) Passenger Demand Matrix





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Calculation of Optimum Rank at Minimum Total Cost

Case 1: ***Optimized Regular and Express Bus Headways***

Case 2: ***Optimized Equal Headways***

Case 3: ***Policy Headways (10 min, 20 min, 30 min)***

Parameters Considered

Number of Bus Stops: 160
Bus Type: Standard Buses

Value of Riding Time: 5 ($/hour/Pass)
Value of Waiting Time: 10 ($/hour/pass)

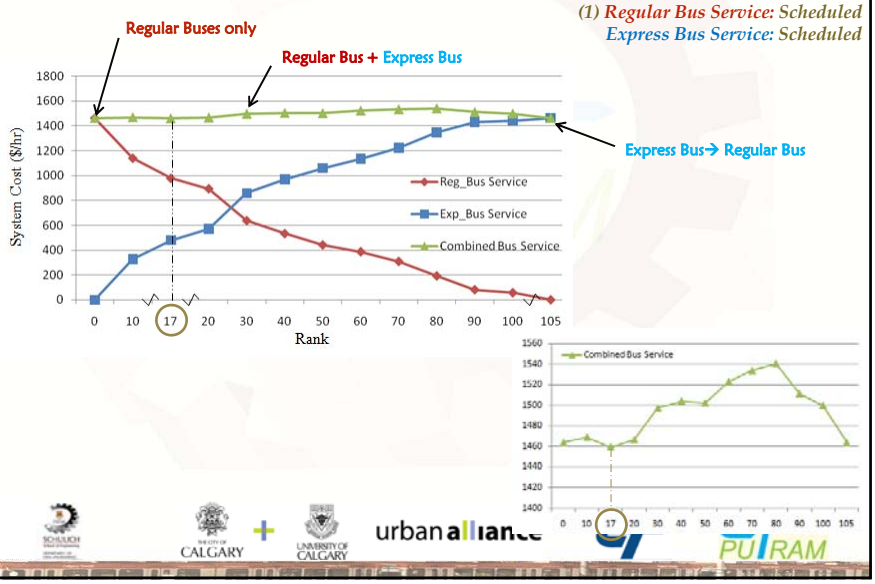
Dwell Time per stop: 40 (sec)
Cruising Speed (Regular & Express Bus): 60 (km/hour)
Bus Capacity (Regular & Express Bus): 80 (passengers)
Rate of Acceleration, Deceleration: 0.4 (m/s^2)
Layover Time: 30 (min)
Value of Bus Operation (Regular & Express Bus): 40 ($/hr/bus)

Optimum Rank at Minimum Total Cost

Case 1: Optimized Regular and Express Bus Headways (Square Root Policy)

Service Type:

(1) Regular Bus Service: Scheduled
Express Bus Service: Scheduled

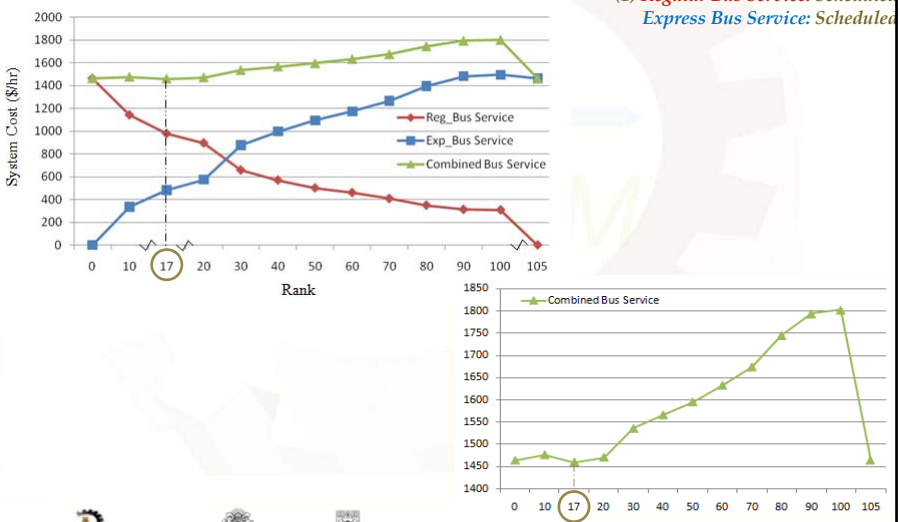


Optimum Rank at Minimum Total Cost

Case 2: Optimized Equal Headways

Service Type:

(1) Regular Bus Service: Scheduled
Express Bus Service: Scheduled

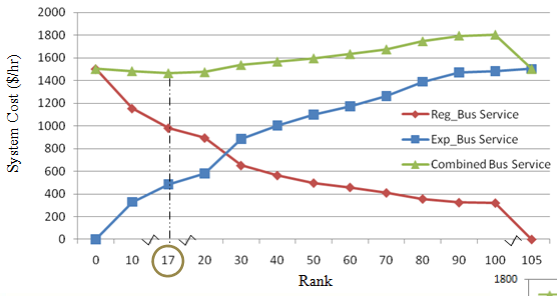


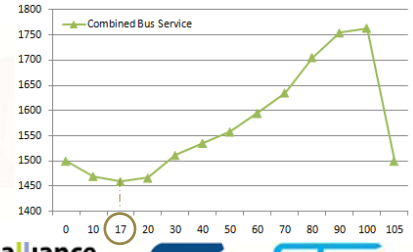
Optimum Rank at Minimum Total Cost

Case 3: Policy Headways (10 min, 20 min, 30 min)

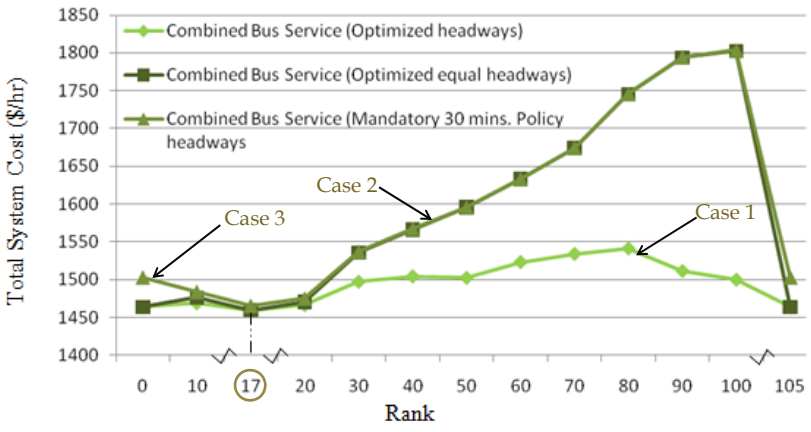
Service Type:

(1) Regular Bus Service: Scheduled
Express Bus Service: Scheduled



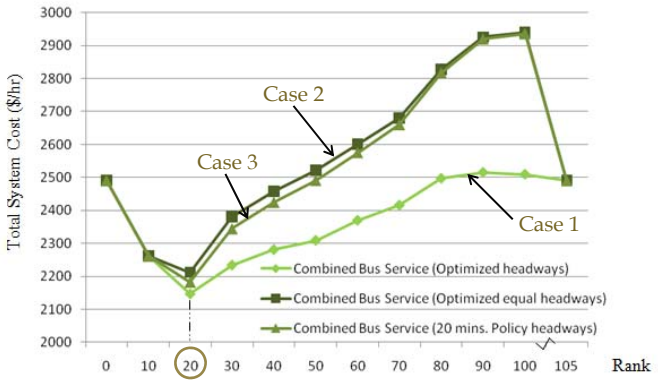


Optimum Rank at Minimum Total Cost



Cost Saving : 0.3%, Travel Time Savings: 58%

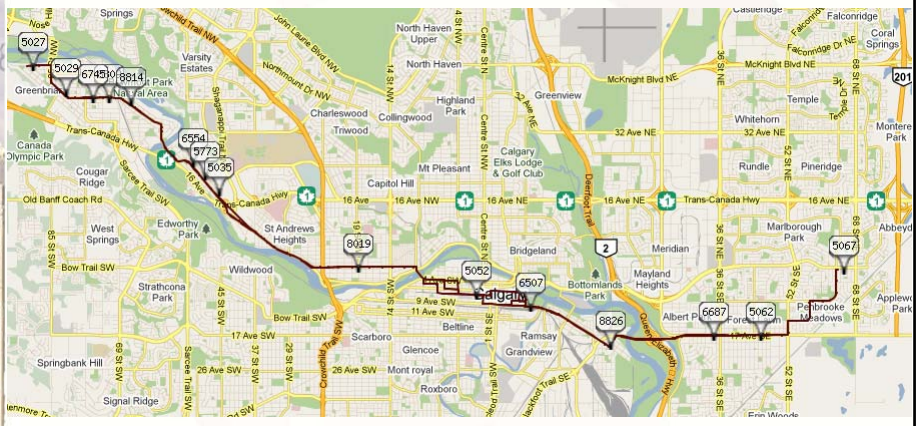
Optimum Rank at Minimum Total Cost for Increased Passenger Demand by 3X on Route 1



Cost Saving : 13.8 %, Travel Time Savings: 55%

Express Bus Stop Locations on *Bus route 1 (Forest Lawn /Bowness)*

(15 Bus stops in one direction out of 80 Bus Stops)



Express Bus Stop Locations:

5027, 5029, 6745, 8809, 8814, 6554, 5773, 5035, 8019, 5052, 6507, 8826, 6687, 5062, 5067, 8275, 5075, 5077, 7251, 5001, 8839, 5018, 7876, 8799, 8821, 6742, 5024, 7487, 8812

Conclusions

- *Urban Public transit modes must be defined with more clarity.*
- *There is significant variation in the data available on maximum flow and mean speed of various transit modes mostly due to variations in input parameters.*
- *The maximum flow and mean speed data show ranges that are mainly outside those reported by Vuchic.*
- *One can transition from one urban public transit mode to another if the optimized total cost (cost to the passengers plus cost to the operator) of the new mode is lower.*
- *In the case of transition from a regular bus route to a combined regular plus express bus route, one can optimize the latter with respect to the portion of the route on which express buses operate and their headway, as well as the new headway of regular buses.*
- *An analytical model provides insights while a spreadsheet model can be used to estimate the system parameters.*

Continental Distribution of Data

Transit Mode	Number of Observed Capacity Data (Continental Distribution)	Number of Observed Average Speed Data (Continental Distribution)
Regular Bus	Europe -1; North America - 14	Europe - 4; North America – 5; South America – 1; Asia – 7; Oceania – 2; Africa – 1; Undefined - 3
Express Bus	North America - 21	North America – 6; South America – 3; Asia – 1; Oceania – 1; Undefined - 1
Bus Rapid Transit	Europe - 2 ; North America – 18; South America – 7; Asia – 3; Africa – 7; Undefined - 1	Europe - 9 ; North America – 13 ; South America – 6 ; Asia – 4 ; Undefined - 2
Busways	North America – 11 ; South America – 21; Asia – 15 ; Africa – 2; Oceania – 2; Undefined - 1	Europe -2; North America – 11 ; South America – 25 ; Asia – 11; Africa – 2; Oceania – 3 ; Undefined - 1
Light Rail Transit	Europe - 3 ; North America – 16 ; Asia – 3 ; Africa – 6; Undefined - 2	Europe – 29; North America – 18 ; South America – 1 ; Asia – 5 ; Africa – 4; Oceania – 1; Undefined - 1
Metro	Europe - 1 ; North America – 1; South America – 4; Asia – 1; Undefined - 3	Europe - 3 ; North America – 4; South America – 1; Asia – 6; Undefined - 4