

# **Economic Assessment of a Dynamic Autonomous Road Transit (DART) System for Singapore**

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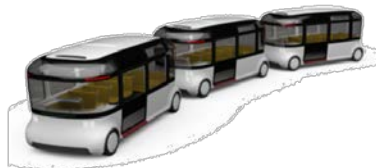
27 AUG 2019

# A solution of autonomous vehicles

## Dynamic Autonomous Road Transit (DART) System



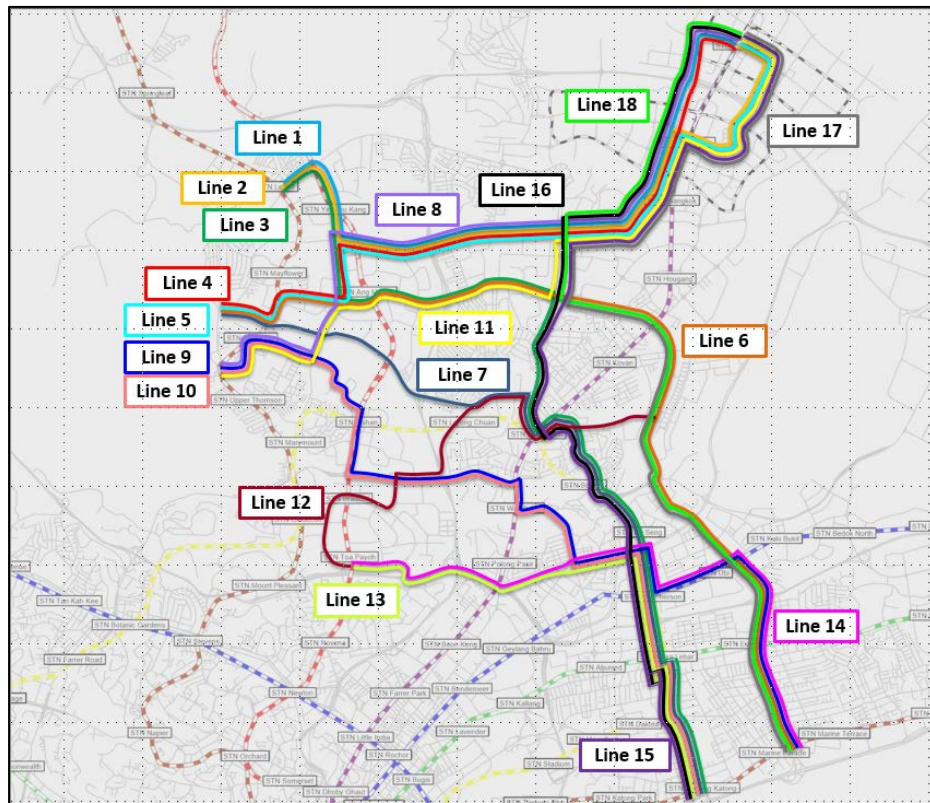
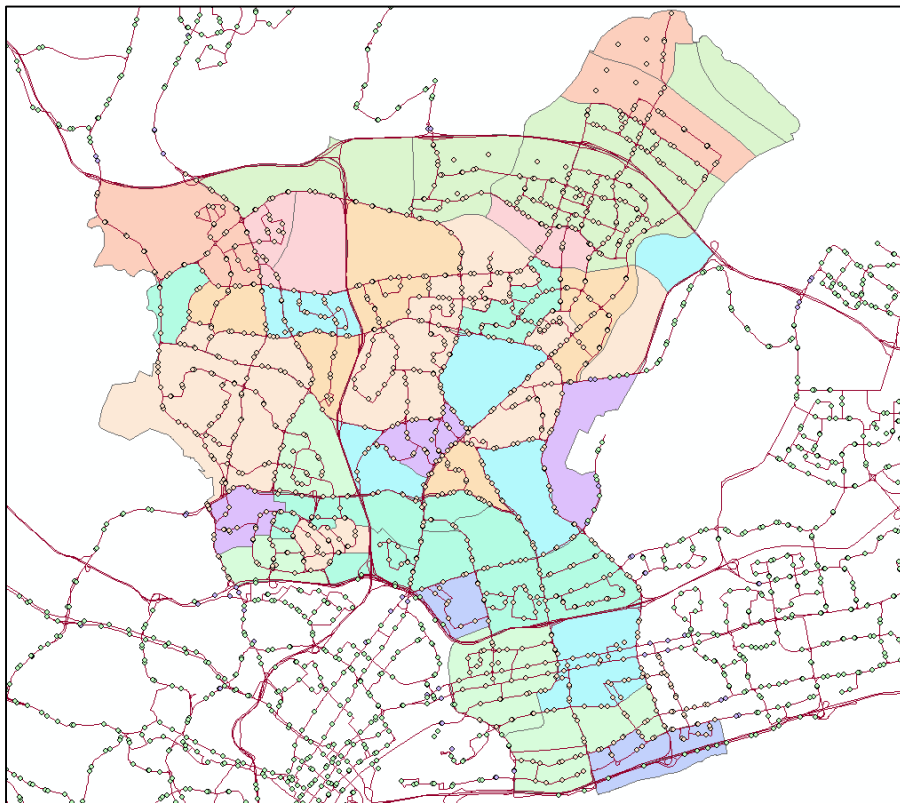
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# Contents

Dimensions	Bus system (existing)	DART system (being proposed)
network	decompose	developed
total cost of ownership	estimate	estimate
cost and efficiency	calculate	calculate
willingness to shift	stated-preference survey	

# Decomposing the bus fleet

$$AF = \sum_{j=1}^m f_j * \frac{s_j}{t_j}$$

where,

$AF$  : assigned bus fleet size

$j$  :  $j_{th}$  bus service

$f_j$  : bus fleet size of  $j_{th}$  service

$t$  : total bus stops

$s$  : number of stops within study area

Operator	# Bus	Service in total	Service in study area
SBS	2,616	153	102
SMRT	1,056	47	12
Go-Ahead	300	19	15
Tower Transit	300	18	2
Sum	4,272	237	131

December, 2018.

# Estimating total cost – acquisition cost

Module	Specification	Market price	Sources
Alexander Dennis Enviro500	DD	248,756	Alexander Dennis Enviro500 (2018, January). Retrieved from: <a href="https://landtransportguru.net/alexander-dennis-enviro500/">https://landtransportguru.net/alexander-dennis-enviro500/</a>
Volvo B5LH (electric)	SD	862,300	Danisha Hakeem (2018, October). Electric buses in Singapore to cost approximately double than those in Shenzhen under the same operator? Retrieved from: <a href="https://www.theonlinecitizen.com/2018/10/30/electric-buses-in-singapore-to-cost-approximately-double-than-those-in-shenzhen-under-the-same-operator/">https://www.theonlinecitizen.com/2018/10/30/electric-buses-in-singapore-to-cost-approximately-double-than-those-in-shenzhen-under-the-same-operator/</a>
Volvo B9TL	DD	580,000	Volvo B9TL. (2018, January). Retrieved from: <a href="https://en.wikipedia.org/wiki/Volvo_B9TL#Singapore">https://en.wikipedia.org/wiki/Volvo_B9TL#Singapore</a>
Volvo B10TL	DD	580,000	Assumed
Volvo B10BLE	SD	367,500	Assumed
Mercedes-Benz O530 Citaro	SD	473,988	Mercedes-Benz Citaro (2018, January). Retrieved from <a href="https://landtransportguru.net/mercedes-benz-citaro/">https://landtransportguru.net/mercedes-benz-citaro/</a>
Mercedes-Benz OC500LE	SD	473,988	Assumed
Mercedes-Benz O405G	SD	473,988	Assumed
Scania K230UB	SD	367,500	Green Efforts (2008, September). Retrieved from <a href="https://www.sbstransit.com.sg/about/social.aspx">https://www.sbstransit.com.sg/about/social.aspx</a>
MAN A95 ND323F	DD	488,220	111 Euro 6 Double Deck buses procured by LTA (2018, July). Retrieved from <a href="https://landtransportguru.net/euro-6-double-deck-buses-procured-by-lta/">https://landtransportguru.net/euro-6-double-deck-buses-procured-by-lta/</a>
MAN A22 NL323F	SD	367,500	Assumed
DART	SD	225,000	Ongel, A., Loewer, E., Roemer, F., Sethuraman, G., Chang, F., & Lienkamp, M. (2019). Economic Assessment of Autonomous Electric Microtransit Vehicles. Sustainability, 11(3), 648.

# Estimating total cost – operation & maintenance cost

		Conventional bus		DART
Cost categories	Units	SD	DD	SD
Road Tax	Registration fees (S\$ per unit)	220	220	220
	Additional registration fees (S\$ per unit)	2,450	2,450	4,000
	Certificate of entitlement (COE)	27,009	27,009	27,009
	Road tax (S\$/6 months)	391	553	391
Fuel/energy	(per litre diesel or per kWh)	1.19	1.19	0.258
	Efficiency (S\$/km)	0.63	0.63	1.25
Insurance	(S\$ per unit year)	6,889	6,889	6,889
Bus driver	Gross salary (S\$ per driver-month)	4,000	4,000	0
	Driver-Bus ratio	1.85	1.85	0

$$TCO_i = \sum_{i=1}^n \frac{A_i(1-e) + M_i + O_i}{(1+r)^{i-1}}$$

where,

$TCO$ : Annual total cost of ownership;

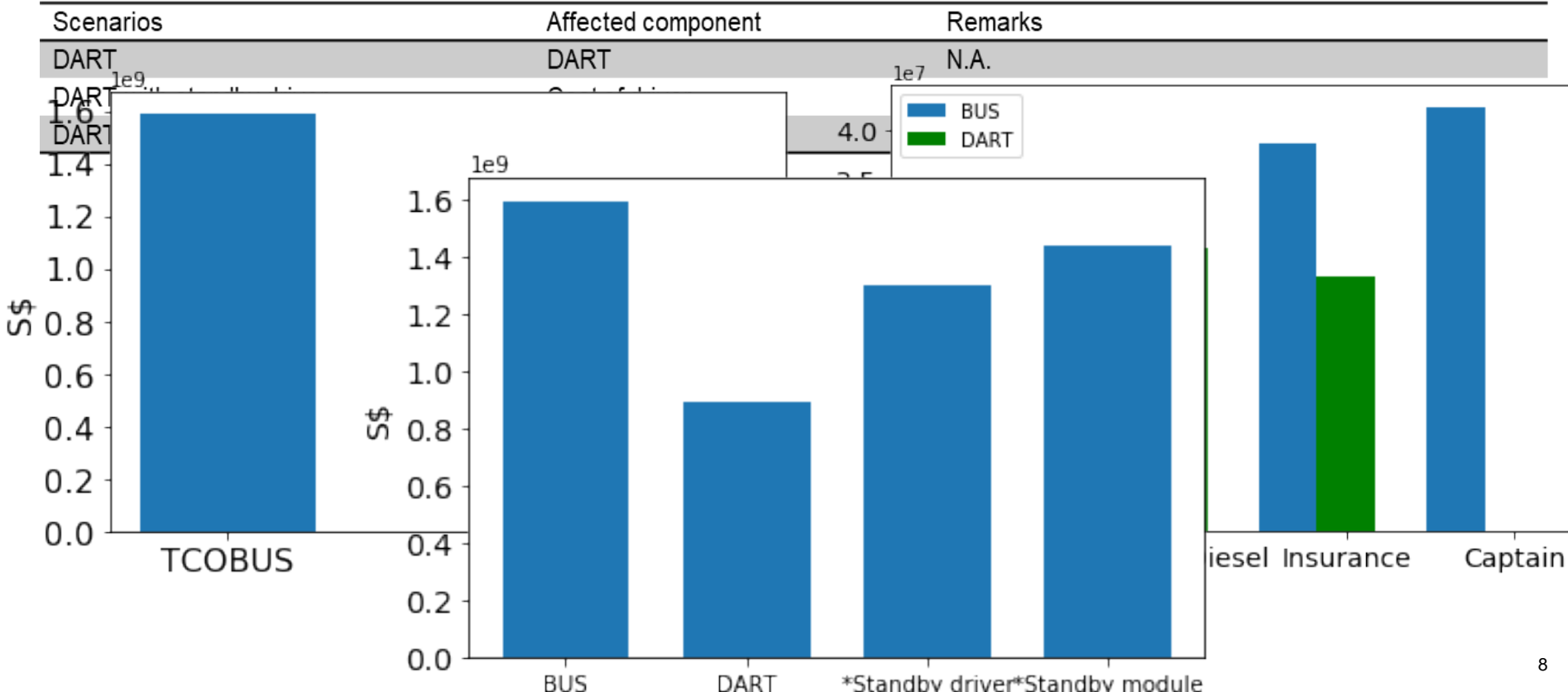
$A_i$ : Acquisition cost as assigned;

$M_i$ : Maintenance cost;

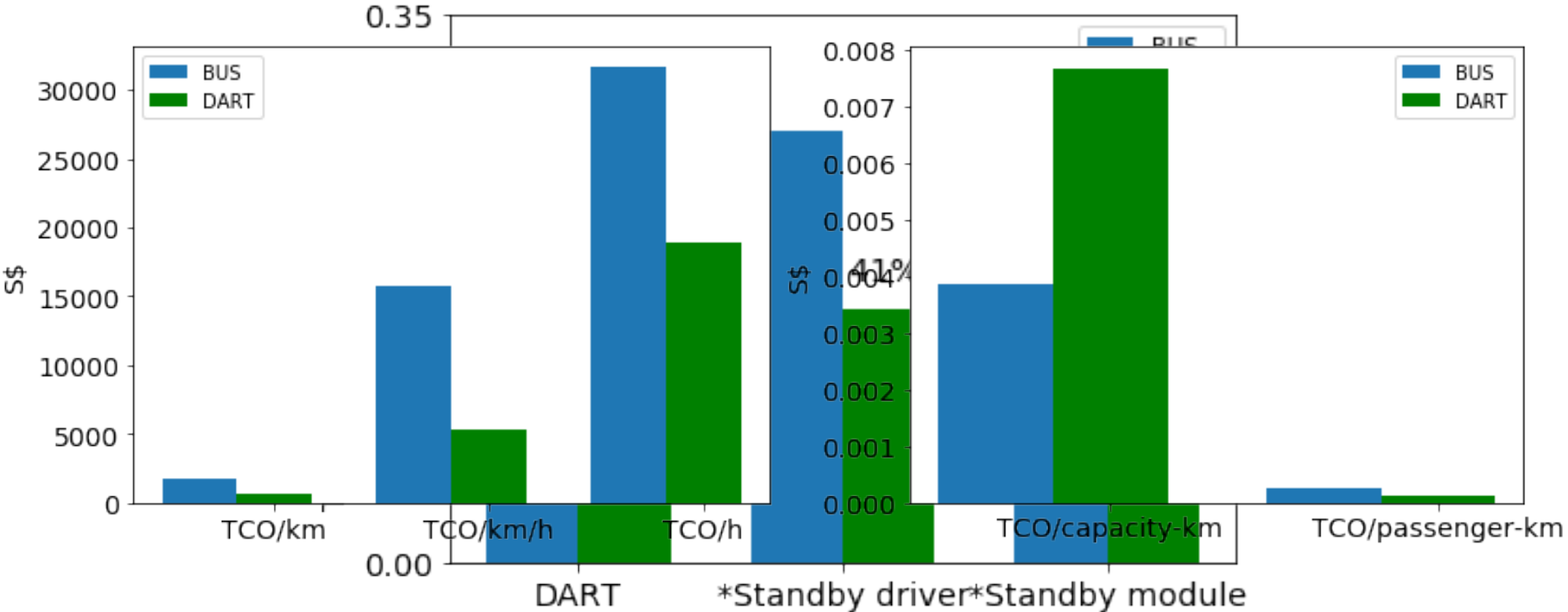
$O_i$ : Operation cost;

	Conventional bus	DART	Comparison (%)
Average days of operation per year	329	329	Same
Average distance travelled/day, km	162	213	Longer by 30.7
Operating speed, km/h	19	28	Faster by 47.5
Capacity	87 – 133	30 – 300	Dynamic

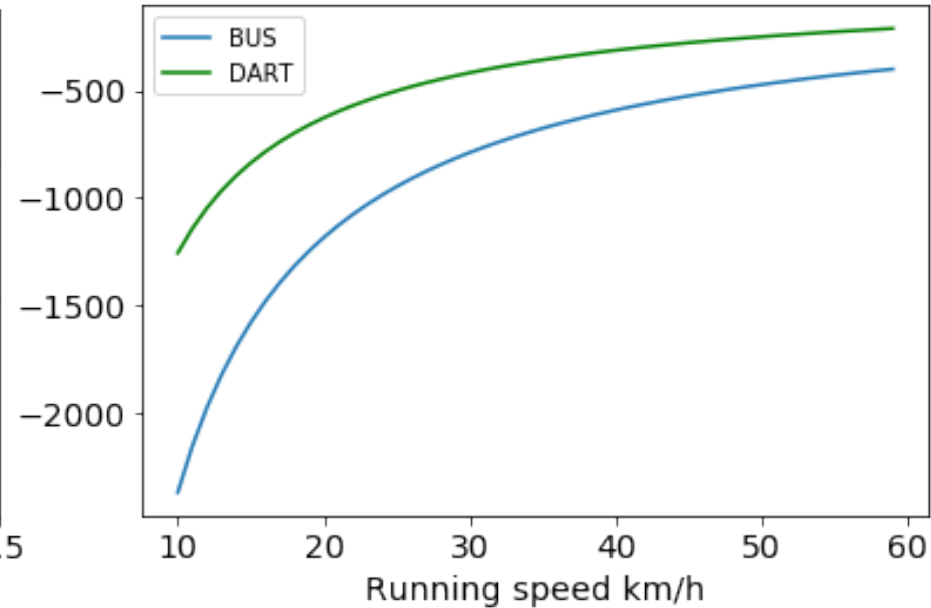
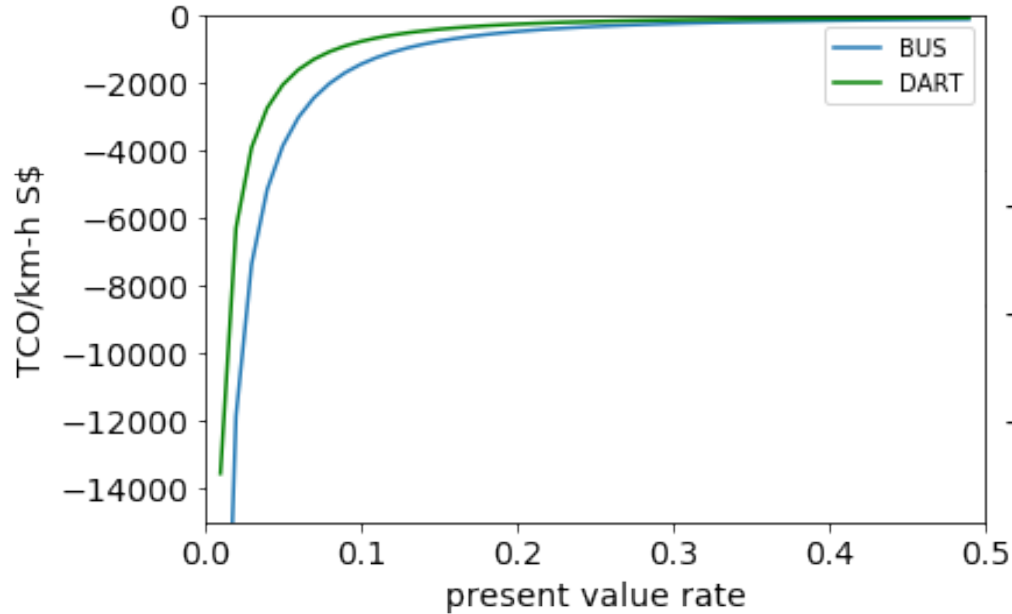
# Comparing scenarios – results



# Calculating cost efficiency results



# Sensitivity analysis



Demographic	Count	Category	Number of respondents	Share (%)
Gender	204	Male	119	58.33%
		Female	85	41.67%
		Mean	34	N/A
Age (years)	196	Median	31	N/A
		Standard Deviation	15	N/A
		Basic	30	14.78%
Education	203	Technical	6	2.96%
		High school	28	13.79%
		College	128	63.05%
Occupation	199	Full-time	120	60.30%
		Part-time	18	9.05%
		Student	52	26.13%
Car ownership	204	Other	9	4.41%
		Yes	46	22.55%
		No	158	77.45%
Preferred walking time (minutes)	204	0-5	105	51.47%
		6-10	58	28.43%
		11-15	38	18.63%
Preferred waiting time (minutes)	204	>15	3	1.47%
		01-05	93	45.59%
		6-10	62	30.39%
Activity in-vehicle	203	11-15	46	22.65%
		>15	3	1.47%
		Work-related	71	34.98%
		Non-work related	109	53.69%
		Others	23	11.33%

## Working area

(Republic Plaza, 9 Raffles Place,  
Singapore 048619)

## Shopping centre

(Orchard Central, 181 Orchard Rd,  
Singapore 238896)

## Recreation centre

Basketball Association of Singapore,  
601 Aljunied Avenue 1, #01-04,  
389862

## HDB

(Block 403 HDB Serangoon, 403  
Serangoon Ave 1, Singapore 550403)

## Apartment

(Terrasse Condo, 21-37 Terrasse Ln,  
544777)

# Multinomial logit model (MNL)

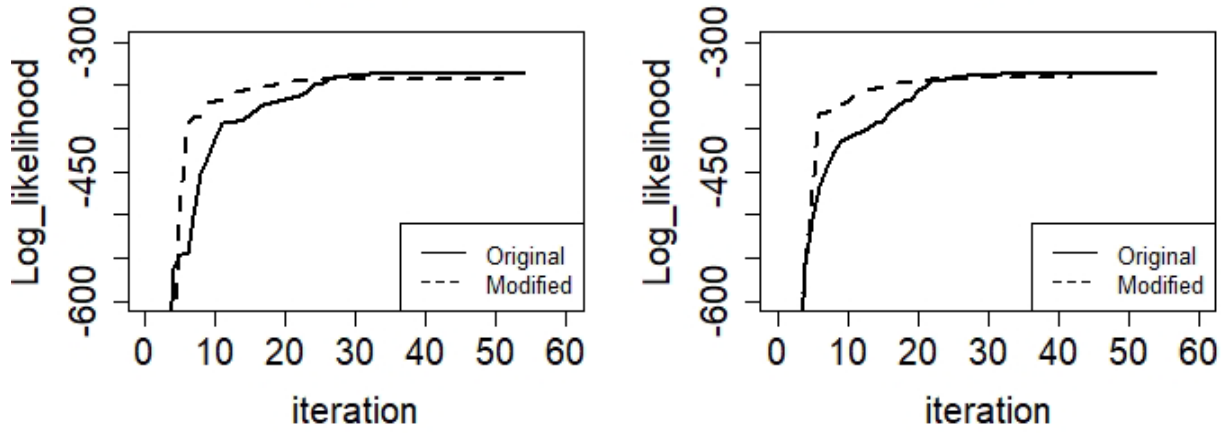
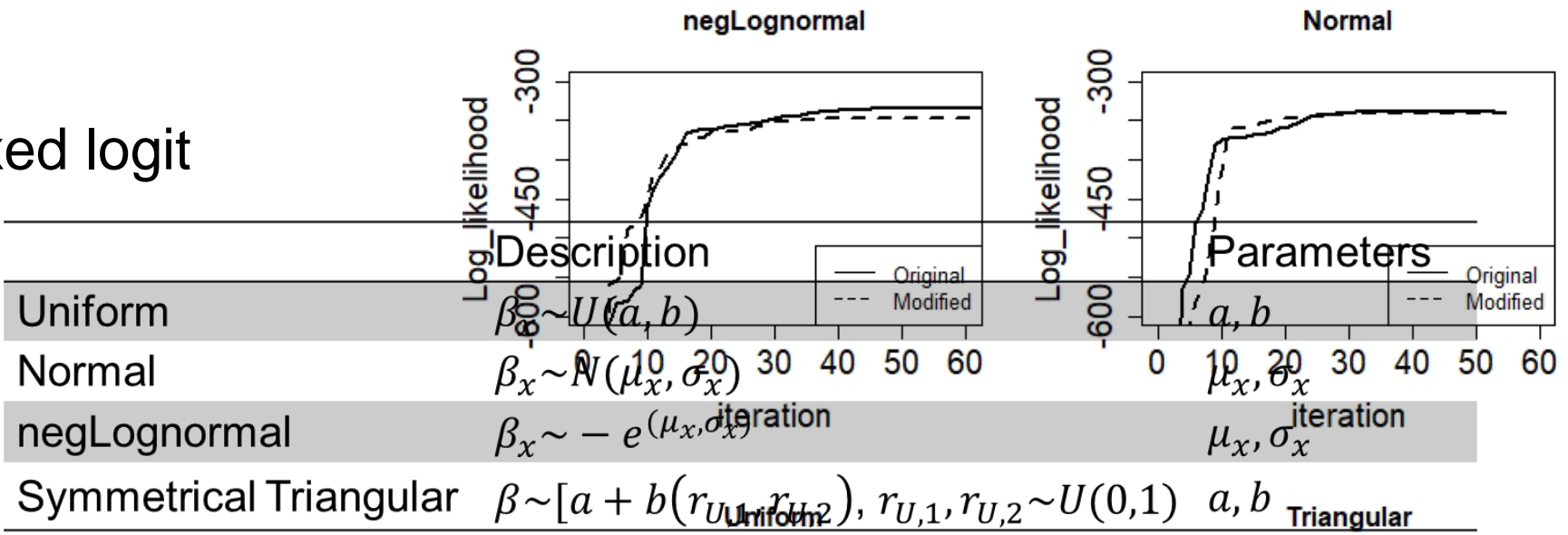
$$U_{n,i} = V_{n,i} + \varepsilon_{n,i} = asc + \beta_{tt} * tt + \beta_{tc} * tc + \varepsilon_{n,i}$$

$$\beta_{tt\_modified} = \beta_{tt} + \beta_{walk} * walk_{time} + \beta_{wait} * wait_{time}$$

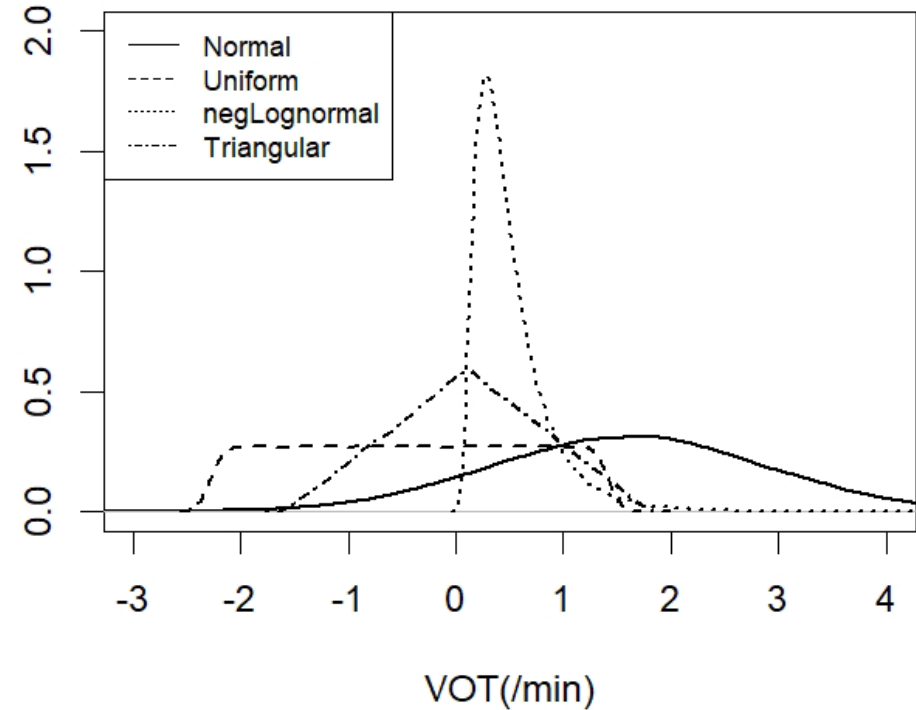
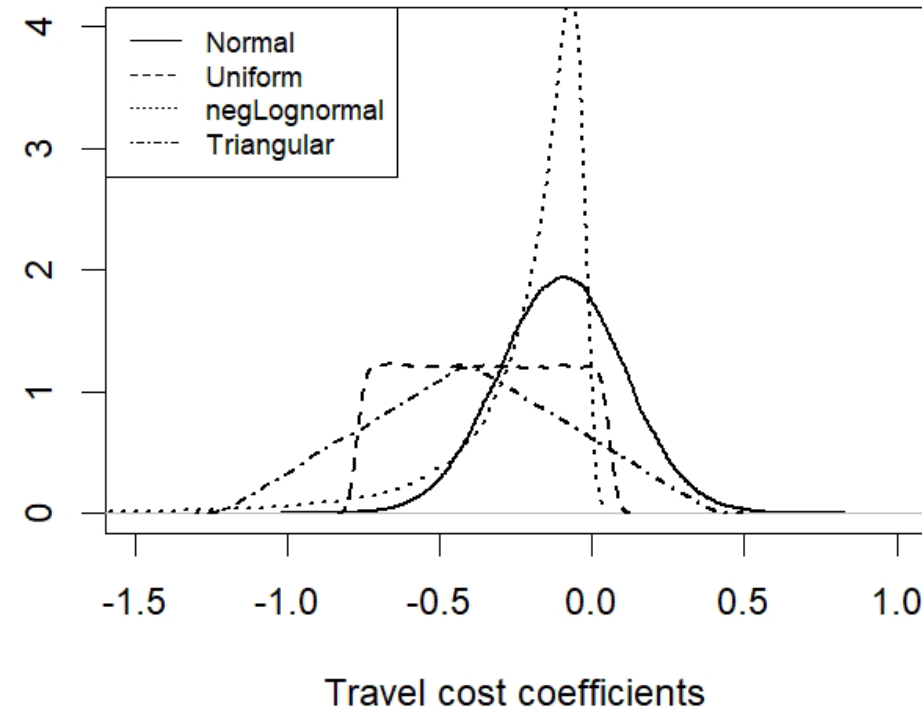
$$\beta_{tc\_modified} = \beta_{tc} + \beta_{in\_veh} * in\_vehicle\_act$$

Indicator	Value	Variable	Estimate	Rob.t-ratio(0)
# subjects	128	<i>asc</i>	-1.494	-1.102
# observations	1024	Female	-0.054	-0.145
# parameters	12	Car ownership	-0.342	-0.866
<i>LL</i> (final)	-506.569	Education	0.271	1.515
Adj. $\rho^2$	0.2694	Occupation	-0.179	-0.977
AIC	1037.14	Age	-0.019	-1.276
		Walking preference	0.008	0.706
		Waiting preference	-0.002	-0.235
		In-vehicle productivity	0.023	1.714
		$\beta_{tt\_taxi}$	-0.037	-1.606
		$\beta_{tt\_pt}$	-0.059	-3.424
		$\beta_{tc}$	-0.078	-2.935

# Mixed logit



# Value of time estimation



# Changes in shares

Scenario 1      Public transport costs less by 10%

Thank you!

SUN Shanshan Oscar

Model	negLognormal	Normal	Triangular	Uniform
Taxi	-0.00253	-0.00229	-0.00294	-0.00334
Public transport	0.00072	0.00101	0.00102	0.00122

Scenario 2      Public transport travels faster by 10%

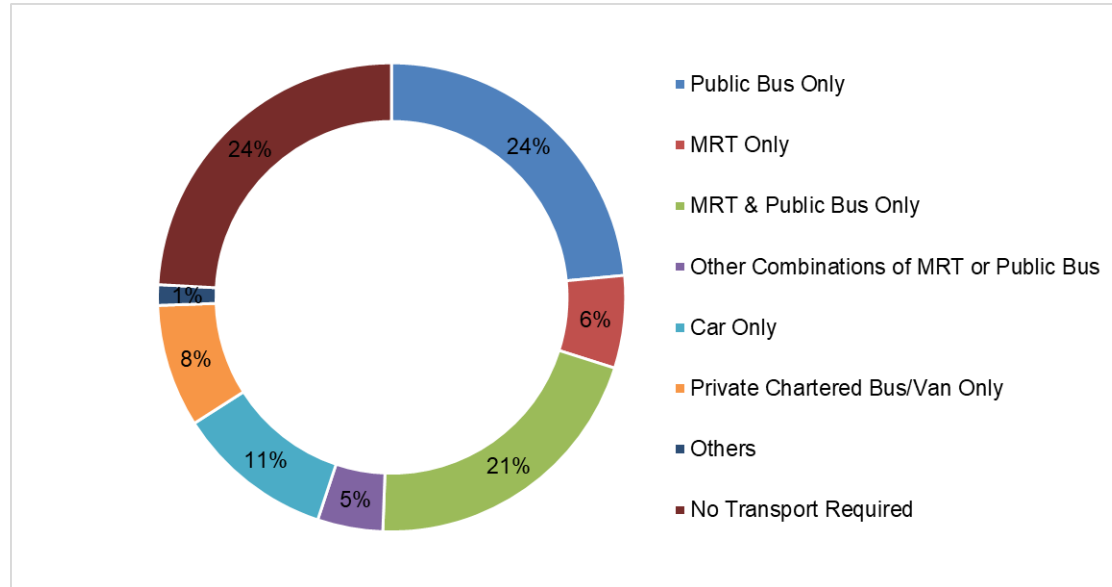
Model	negLognormal	Normal	Triangular	Uniform
Taxi	-0.10358	-0.11046	-0.11289	-0.12646
Public transport	0.02877	0.04242	0.03918	0.04206

# Modelling statistics

Variable/attribute	negLognormal		Normal		Triangular		Uniform	
	estima te	Rob.t- ratio(0)	estima te	Rob.t- ratio(0)	estima te	Rob.t- ratio(0)	estima te	Rob.t- ratio(0)
<i>asc</i>	3.108	0.77	3.630	1.2	2.993	1.14	2.499	0.85
Female	0.650	0.47	0.349	0.59	0.124	0.19	0.007	0.01
Car ownership	-2.116	-2.52	-1.619	-1.27	-1.469	-1.23	-1.794	-1.56
Education	0.105	0.15	-0.039	-0.14	0.058	0.17	0.444	1.24
Occupation	-0.462	-0.47	-0.694	-1.51	-0.527	-0.75	-0.539	-0.77
Age	-0.077	-1.57	-0.082	-2.59	-0.077	-1.33	-0.079	-2.17
Walking preference	0.028	1.63	0.027	1.61	0.024	1.74	0.034	1.69
Waiting preference	-0.031	-2.86	-0.018	-1.49	0.028	1.96	-0.007	-0.38
In-vehicle productivity	0.093	1.59	0.059	2.53	0.064	1.59	0.107	2.83

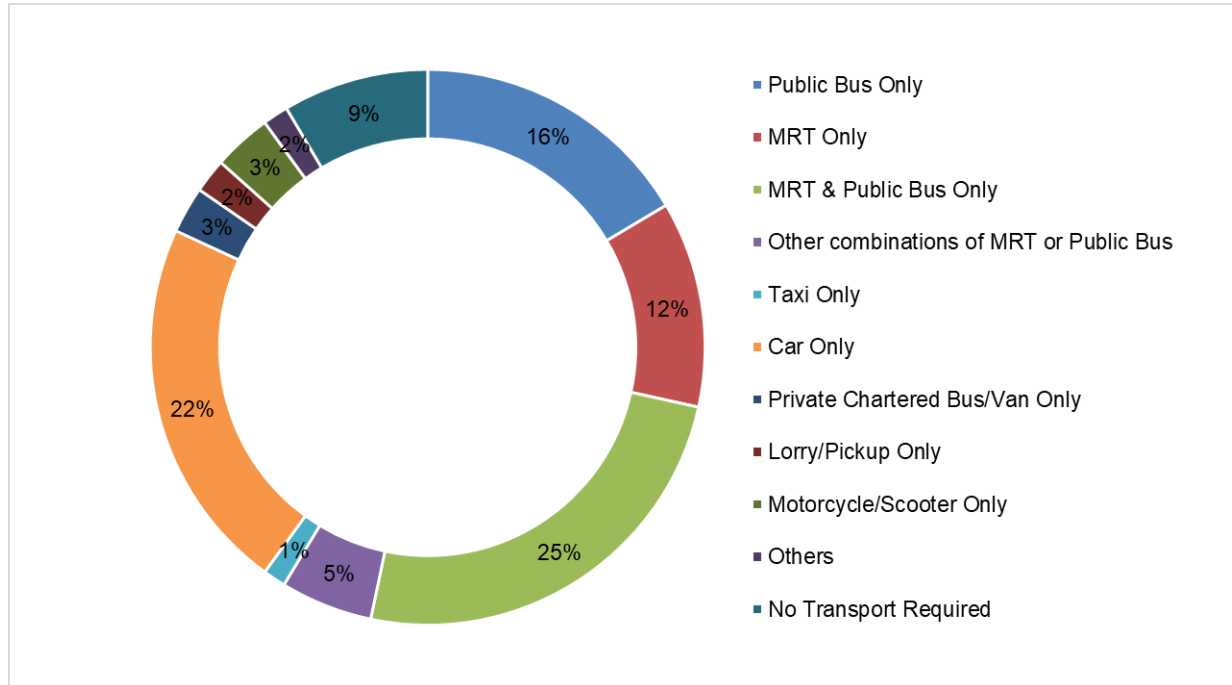
# GENERAL HOUSEHOLD SURVEY 2015

Table 153 Resident Students Aged 5 Years and Over by Usual Mode of Transport *to School*

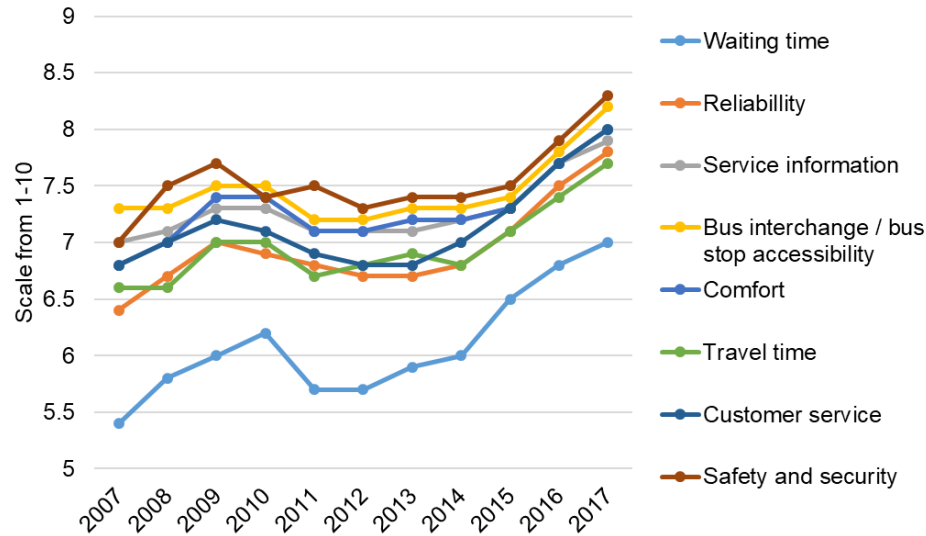


# GENERAL HOUSEHOLD SURVEY 2015

Table 159 Resident Working Persons Aged 15 Years and Over by Usual Mode of Transport *to Work*



Satisfaction mean score



Percentage of commuters satisfied

