

1 **Estimation of new monetary valuations of travel time,**
2 **quality of travel and safety for Singapore**

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25 **ABSTRACT**

26 This paper reports the findings of a large scale study in Singapore to estimate new monetary
27 valuations for travel time, quality of travel, and safety, covering different modes and journey
28 components. A wide ranging stated choice survey was conducted on a large and representative
29 sample. The empirical work pushed the boundaries of the international state-of-practice in choice
30 modelling by relying on Mixed Logit models with all model components being random and a full
31 covariance matrix being estimated. We present detailed results and contrast the values to those from
32 the previous study conducted in 2008.

33

34 *Keywords:* value of time (VTT), value of risk reduction, stated choice, Singapore

35

36 1. INTRODUCTION

37 The Land Transport Authority (LTA) is the government agency tasked with the development and
 38 regulation of Singapore's land transport system. In common with many other such agencies around
 39 the world, LTA uses cost-benefit analysis as part of its overall appraisal framework in determining the
 40 merits of new transport policies and infrastructure developments. For this, social benefits such as
 41 travel time savings, reliability improvements, crowding reductions and accident cost savings need to
 42 be quantified. Willingness to pay (WTP) measures are critical inputs into this process, and, in
 43 common with many other national bodies (see e.g. [1,2,3,4]), LTA makes use of values produced
 44 through the estimation of discrete choice models on stated preference (SP) data.

45 With the major societal, economic and environmental implications of new policy and
 46 infrastructure schemes, it is important that these WTP measures have a high level of reliability. This
 47 means that the values should be updated at regular intervals given not only the changing nature of
 48 transport systems and travel behaviour, but also ongoing improvements to survey and modelling
 49 approaches.

50 As the most recent WTP estimates dated from 2008, LTA commissioned a new study in 2015,
 51 with a large scale data collection effort and the estimation of advanced choice models, offering
 52 improvements in flexibility over those used in 2008. What sets the resulting study apart is the relative
 53 size of the sample compared to the population of Singapore, the breadth of modes and journey
 54 components covered, and the use of a highly flexible treatment of heterogeneity. This latter point
 55 ensures a methodological contribution on top of the development of new results for policy work.

56 2. SURVEY WORK

57 2.1. Sampling¹

58 A total of 5,000 households were selected for interview between May and November 2015,
 59 representing a very large sample from a population of around 5.6 million people. Quotas were
 60 developed by travel mode, journey purpose, period of travel, age and gender, ensuring sufficiently
 61 large sample sizes for the modelling work for each mode as well as representative samples for other
 62 dimensions. The study sampled car, motorcycle, MRT (Mass Rapid Transit), bus and taxi users as
 63 well as pedestrians and cyclists.

64 The vast majority of interviews were carried out in respondents' homes using tablets. This data
 65 was supplemented with some additional observations from an island wide intercept survey. Upon
 66 successful completion of a survey, each respondent was given a \$10 online shopping voucher as a
 67 reward.

68 Before analysis, the sample was compared with the 2012 household travel survey (HTS) data
 69 to test its representativeness. While this showed small discrepancies, e.g. a slightly higher percentage
 70 of 35-54 year olds and female respondents in the survey, the overall match was very good, also in
 71 terms of dwelling types, vehicle ownership, ethnic breakdown, employment status and income
 72 distribution.

73 2.2. Survey contents and design

74 Stated preference, and in particular stated choice (SC), is a widely used technique for value of time
 75 (VTT) research (cf. reviews in [2]). Respondents are faced with a number of carefully designed
 76 hypothetical choice scenarios, where in each scenario, two or more alternatives are described by key
 77 attributes such as travel time and travel cost, and the respondent is asked to select their preferred
 78 option in each.

79 There is ongoing debate in the academic literature about the relative merits of 'simple' and
 80 'complex' surveys. Much of the Northern European evidence is based on the most simplistic two
 81 alternative two attribute (cf. discussions in [2]). On the other hand, work especially in Australia tends
 82 to rely on at least three alternatives in each choice task, with often five or six attributes describing
 83 them (see e.g. [5]). In our work, we strike a balance between these two extremes. While we retain a
 84 binary context, we use a larger number of attributes to describe these alternatives. With substantial
 85 differences across the various measures we are interested in (e.g. VTT vs value of safety), we

¹ Details on quotas and socio-demographics in the final sample are available from the first author on request.

86 however spread the choice tasks for each respondent across different survey contexts, or games, also
 87 helping to reduce respondent burden.

88 An overview of the different SC games is given in Table 1, where, for example, car users
 89 faced 15 choice tasks spread across three different games. For the majority of attributes, we sought to
 90 increase realism by pivoting the values presented to respondents around the attributes from a recent
 91 trip for that respondent. The actual designs were produced using NGene², with Bayesian D-efficiency
 92 as a criterion for the statistical properties of the designs (cf. [6]), priors coming from the 2008 study
 93 ([7]), and avoiding the inclusion of strictly dominant alternatives by using a regret measure [8]. The
 94 majority of the games are of such standard nature that no details are required beyond those in Table 1.
 95 Special attention however is needed for accident games (CA1, MCA1, PA1 and CYA1), crowding
 96 games (MT1 and BT1) and the bus excess waiting time game (BT2).

97
 98 **Table 1: Summary of different SC games**

Game	Description	Attributes	Choice tasks
CT1	Car: congestion & costs	Free flow travel time, light congestion, heavy congestion; Parking cost, petrol cost, ERP (electronic road pricing) cost	5
CT2	Car: parking choice	Walking time, queuing time, search time; Parking cost	5
CA1	Car: accidents	Fatalities, serious and light injuries per year; Change in annual tax burden	5
MCT1	Motorcycle: congestion & costs	Free flow travel time, light congestion, heavy congestion; Parking cost, petrol cost, ERP cost	7
MCA1	Motorcycle: accidents	Fatalities, serious and light injuries per year; Change in annual tax burden	5
MT1	MRT: time & crowding	Walking time, waiting time, in vehicle time in five crowding levels (3 seated, 2 standing), interchanges; Fare	7
MT2	MRT: walking	Crossing type (at grade, uncovered bridge, covered bridge without lift, covered bridge with lift, airconditioned underpass; Covered and uncovered walking time to and from crossing Fare	7
BT1	Bus: time & crowding	Walking time, waiting time, in vehicle time in five crowding levels (3 seated, 2 standing), interchanges; Fare	7
BT2	Bus: excess waiting time	Bus arrival times; Fare	7
TT1	Taxi: access, time & costs	Walking time, waiting time, in vehicle time; Prebooked or on-street; Fare, booking fee	7
PT1	Pedestrian: walking environment	Crossing type (at grade, uncovered bridge, covered bridge without lift, covered bridge with lift, airconditioned underpass; Covered and uncovered walking time to and from crossing	7
PA1	Pedestrian: accidents	Fatalities, serious and light injuries per year; Change in annual tax burden	5
CYA1	Cycling: accident	Fatalities, serious and light injuries per year; Change in annual tax burden	5

99
 100 The purpose of the accident games is to derive a WTP for reducing the number of different
 101 types of accidents and hence also the WTP for reducing personal risk. A standard approach (e.g. [9])
 102 involves presenting respondents with a choice between two routes described in terms of travel time,
 103 the number of accidents by injury types, and some monetary cost, with the choice framed around a
 104 recent journey and accident rates presented as e.g. “*Number of deaths per year along the route...*” In
 105 [9], this number goes from 0 to 5, which is of course very high for a single road.

² <http://www.choice-metrics.com>

106 In the case of Singapore, where the total number of accidents is far lower, presenting per
 107 road/route rates is even more unrealistic. There is also an issue with exposure, as only part of
 108 someone's annual travel will be on this route, and a disconnect between the payment mechanism (per
 109 trip) and the accident numbers (per year). A per journey cost also makes the method inapplicable for
 110 pedestrians and cyclists. We instead rely on a *programme* approach, where the choice is between two
 111 national safety programmes, with the payment mechanism being a change in annual tax burden. The
 112 two programmes are described in terms of increases or decreases in tax (per year), along with annual
 113 figures for fatalities, serious and slight injuries.

114 MT1 and BT1 look at the sensitivity to in vehicle travel time in different conditions, waiting
 115 time, walking time and interchanges. Rather than simply presenting overall numbers for a journey and
 116 a single level of crowding, we show journeys broken up into differently sized stages (cf. **Error!**
 117 **Reference source not found.**). The presentation allows for changes in crowding that are the result of
 118 either changing to a different bus/train or other passengers joining/leaving the bus/train the respondent
 119 is already travelling on.
 120

	OPTION A	OPTION B
Bus BT1 Time	49 minutes	44 minutes
Total Journey Time	0	1
Interchanges	3 minutes	4 minutes
Walking Time	6 minutes	10 minutes
In Vehicle Time	40 minutes	30 minutes
Fare (\$)	\$1.70	\$2.30

I would choose:	OPTION A	OPTION B
<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>

	You WALK for 3 minutes to your first stop		You WALK for 4 minutes to your first stop
	You WAIT for 6 minutes for your bus		You WAIT for 6 minutes for your bus
	You board and SIT for 4 minutes in DENSELY PACKED CONDITIONS		You board and SIT for 13 minutes in DENSELY PACKED CONDITIONS
	You SIT for the next 36 minutes with SOME FREE SEATS AROUND YOU		You leave the bus and WAIT 4 minutes for your next bus
			You board and SIT for 13 minutes in DENSELY PACKED CONDITIONS
			You SIT for the next 4 minutes with SOME FREE SEATS AROUND YOU

121
 122 **Figure 1: Example choice task for BT1**

123 BT2 is concerned with bus reliability. LTA uses the concept of Excess Wait Time (EWT),
 124 where, assuming a uniform arrival rate of passengers, EWT is the average additional wait time actually
 125 experienced compared to the expected wait time if buses arrived at regular intervals. It is defined as the
 126 difference between Actual Wait Time (AWT) and the Scheduled Wait Time (SWT), i.e. $EWT = AWT$
 127 $- SWT$, with:

128

$$AWT = \frac{\sum_n actual\ headway_n^2}{2 \times \sum_n actual\ headway_n}; \quad SWT = \frac{\sum_n scheduled\ headway_n^2}{2 \times \sum_n scheduled\ headway_n} \quad (1)$$

129 EWT increases if there is bus bunching which results in prolonged waits for the subsequent bus.
 130 Respondents had the choice between two future hypothetical bus services (cf. **Error! Reference source**
 131 **not found.**), where the scheduled arrival time of the bus is shown (every 10 minutes), along with the
 132 interval between buses for both options, and the bus fare. It is assumed that buses arrive frequently

133 enough that users “forget the timetable”; in other words, their arrival time at the bus stop is completely
 134 arbitrary.

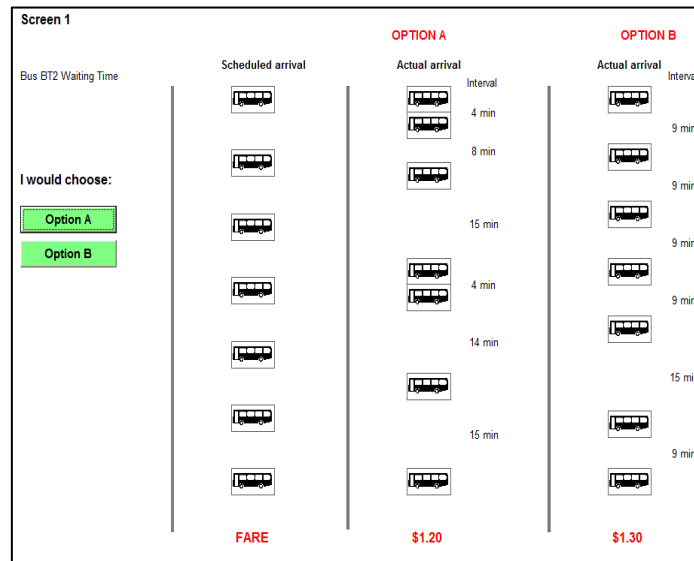


Figure 2: Example choice task for BT2

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138 3. MODELLING FRAMEWORK

139 In the last four decades, choice models have undergone major developments in terms of flexibility,
 140 especially in terms of the presentation of heterogeneity in preferences across individual decision makers
 141 (see e.g. [10]). There have as a result been substantial improvements to the techniques used in VTT
 142 studies, most notably starting with the work in Denmark [4] and more recently in the context of the GB
 143 VTT study [2]. In what follows, we focus only on what’s relevant for the present study, largely for
 144 space considerations.

145 In a random utility model, the utility U_{int} that individual n (out of N) obtains from choosing
 146 alternative i (out of I) in choice situation t (out of T_n) is decomposed into an *observed* component V_{int}
 147 and a random component ε_{int} . Almost all applications rely on an additive error structure, with $U_{int} =$
 148 $V_{int} + \varepsilon_{int}$, where noise is independent of observed utility. Recent work by [11] has questioned this and
 149 put forward a multiplicative formulation, where errors are proportional to observed utility, with $U_{int} =$
 150 $V_{int} \cdot \varepsilon_{int}$. In practice, this implies more noise on longer trips, a notion which has received empirical
 151 support in the Danish [4] and British [2] national studies. We compared the two specifications in early
 152 work, and found no evidence of improvements with the multiplicative structure, allowing us to retain
 153 the additive structure. Part of the reason could be the smaller size of Singapore and the much reduced
 154 heterogeneity in trip distances that results.

155 We next turn to the specification of the observed component of utility. Using the example of
 156 CT1, we would write:

$$157 V_{int} = \beta_{FF}FF_{int} + \beta_{LC}LC_{int} + \beta_{HC}HC_{int} + \beta_{ERP}ERP_{int} + \beta_{petrol}petrol_{int} + \beta_{parking}parking_{int} \quad (2)$$

158 where the time attributes are free flow time (FF), time spent in light congestion (LC), time spent in
 159 heavy congestion (HC), and the cost attributes are ERP, petrol and parking costs, and where we would
 160 estimate six β terms giving the marginal utilities for the associated attributes.

161 The VTT in free flow conditions expressed in terms of ERP cost sensitivity would then for
 162 example be given by $VTT_{FF,ERP} = \frac{\beta_{FF}}{\beta_{ERP}}$, indicating how much increase in ERP would be acceptable
 163 in return for a one minute reduction in free flow time. While these computations are straightforward in
 164 models with fixed β , this is no longer the case when allowing for random heterogeneity (cf. [12]). To
 165 avoid the need to divide by random coefficients, we instead make use of the mathematically
 166 equivalent approach working in WTP space [13], again using ERP as the base cost, such that:

$$167 V_{int} = \beta_{ERP}(VTT_{FF,ERP}FF_{int} + VTT_{LC,ERP}LC_{int} + VTT_{HC,ERP}HC_{int} + ERP_{int}) \\ 168 + \beta_{petrol}petrol_{int} + \beta_{parking}parking_{int} \quad (3)$$

169 where $VTT_{FF,ERP}$ is now estimated directly.

170 Each respondent in our surveys was faced with choice tasks from multiple different games.
 171 While joint estimation would be advisable if valuations were consistent across games, preliminary
 172 work showed differences in valuations across games (not surprising given the differences in context),
 173 and the analysis was carried out on a game specific level, except for merging MT2 and PT1 in the
 174 absence of a cost attribute for the latter.

175 Initial attempts to unearth links between key socio-demographic variables (e.g. income, age)
 176 and patterns in VTT were largely unsuccessful, and we suspected that unexplained heterogeneity
 177 dominated. Our work in this context relies on Mixed Multinomial Logit (MMNL) models (see e.g.
 178 [10], chapter 6), as is now common practice in many national VTT studies (e.g. [1,2,3,4]). Let $P_{int}(\beta)$
 179 give the probability of respondent n choosing alternative i in choice task t , conditional on a vector of
 180 parameters β , where, with ε_{int} following a type I extreme value distribution, we have that $P_{int}(\beta) =$
 181 $\frac{e^{V_{int}}}{\sum_{j=1}^2 e^{V_{jnt}}}$. The probability of the sequence of T_n choices for individual n is given by $P_n(\beta) =$
 182 $\prod_{t=1}^{T_n} \frac{e^{V_{i^*nt}}}{\sum_{j=1}^2 e^{V_{jnt}}}$, where V_{i^*nt} refers to the utility of the alternative n actually chose in task t .

183 We assume that the vector β follows a random distribution across respondents, with $\beta \sim$
 184 $f(\beta | \Omega)$, with Ω a vector of estimated parameters. We then have:

$$185 \quad P_n(\Omega) = \int_{\beta} P_n(\beta) f(\beta | \Omega) d\beta. \quad (4)$$

186 Studies using MMNL typically allow for heterogeneity in only some elements of β and impose
 187 independence between those. As discussed by [14], the first of these assumptions will invariably lead
 188 to lower fit and potential confounding in terms of the source of heterogeneity. The second assumption
 189 will also lead to lower fit and may overstate the heterogeneity in relative sensitivities.

190 In our work, we instead allowed all parameters to vary randomly across respondents, with a
 191 full covariance matrix estimated between them. To the best of our knowledge, this is the first
 192 application doing this in the context of a national VTT study while also going far beyond the level of
 193 flexibility used in the majority of most small scale academic applications.

194 With K elements in β , we would thus estimate K mean sensitivities as well as $\sum_{k=1, \dots, K} k$
 195 elements in the covariance matrix of β . This flexibility comes at the cost of increased model
 196 complexity and classical estimation techniques were found to be unsuitable, in terms of computational
 197 cost and their ability to find meaningful solutions. We instead turned to Bayesian estimation, as
 198 discussed for example by [10] (chapter 13), and specifically the implementation in RSGHB [15].

199 As already mentioned earlier, our initial explorations on the data failed to retrieve meaningful
 200 socio-demographic interactions, and the MMNL models were specified without deterministic
 201 heterogeneity on top of the random heterogeneity. After model estimation, we produced posterior
 202 estimates (see [10], chapter 11), which are then used in posterior segmentation work to attempt to
 203 uncover further deterministic heterogeneity. Let $L(Y_n | \beta)$ give the probability of observing the
 204 sequence of choices Y_n made by respondent n , conditional on a specific value of the vector β . The
 205 probability of observing a specific value of β is then given by Bayes rule as:

$$206 \quad L(\beta | Y_n) = \frac{L(Y_n | \beta) f(\beta | \Omega)}{\int_{\beta} L(Y_n | \beta) f(\beta | \Omega) d\beta} \quad (5)$$

207 It is then possible to simulate for example the most likely value for β for respondent n as:

$$208 \quad \widehat{\beta}_n = \frac{\sum_{r=1}^R L(Y_n | \beta_r) \beta_r}{\sum_{r=1}^R L(Y_n | \beta_r)}, \quad (6)$$

209 where β_r with $r = 1, \dots, R$ are R independent multi-dimensional draws from $f(\beta | \Omega)$.

210

211 4. RESULTS

212 Due to space considerations, we give a detailed account of the results for the CT1 and MCT1 games,
 213 along with overview results for other games.

214 4.1. Detailed results for car and motorcycle in vehicle time games (CT1 and MCT1)

215 We used negative lognormal distributions for the three cost components, and specified the models in
 216 WTP space relative to ERP costs for the three time measures, using positive lognormal distributions,
 217 with a full covariance matrix between the six terms. The three VTT measures were specified in an

218 additive manner, such that we estimate a positive value of free flow time, a positive increase on that
 219 value for travel in light congestion, and an increase on that value for travel in heavy congestion.

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Table 2: Estimation results for CT1 and MCT1

	CT1		MCT1	
Respondents	1,192		107	
Observations	5,960		749	
Estimated parameters	27		27	
Log-likelihood	-3,472.68		-318.15	
adj. ρ^2	0.15		0.34	
	posterior mean	posterior std dev.	posterior mean	posterior std dev.
VTT free flow vs ERP (underlying Normal mean for log of coeff)	-2.33	0.20	-2.13	0.30
VTT light congestion shift vs ERP (underlying Normal mean for log of coeff)	-6.33	0.67	-3.47	0.64
VTT heavy congestion shift vs ERP (underlying Normal mean for log of coeff)	-4.18	0.38	-9.61	1.74
ERP (underlying Normal mean for log of negative of coeff)	-0.51	0.13	0.11	0.18
petrol costs (underlying Normal mean for log of negative of coeff)	-0.97	0.14	0.39	0.19
parking costs (underlying Normal mean for log of negative of coeff)	-0.88	0.12	0.24	0.19
cov(1,1)	3.30	0.84	1.37	0.93
cov(1,2)	2.57	1.08	0.08	0.62
cov(1,3)	2.49	1.60	-0.03	0.75
cov(1,4)	-1.19	0.62	-0.23	0.59
cov(1,5)	-0.79	0.48	-0.21	0.57
cov(1,6)	-0.95	0.53	-0.44	0.66
cov(2,2)	7.33	2.54	0.43	0.43
cov(2,3)	5.53	1.49	-0.04	0.44
cov(2,4)	-3.36	0.79	-0.11	0.38
cov(2,5)	-4.32	1.21	-0.01	0.33
cov(2,6)	-4.28	1.04	-0.08	0.40
cov(3,3)	5.18	2.24	0.52	0.75
cov(3,4)	-2.83	0.86	0.04	0.40
cov(3,5)	-3.34	0.74	-0.02	0.29
cov(3,6)	-3.38	0.79	0.02	0.67
cov(4,4)	1.87	0.48	0.70	0.38
cov(4,5)	2.15	0.42	0.12	0.30
cov(4,6)	2.11	0.40	0.10	0.34
cov(5,5)	3.09	0.64	0.41	0.34
cov(5,6)	2.94	0.48	-0.06	0.26
cov(6,6)	3.03	0.51	0.68	0.49

222 The means of the posterior distributions shown in Table 2 correspond to maximum likelihood
 223 estimates of the individual parameters (cf. 10, chapter 13). These relate to the underlying Normal

224 distributions (a Lognormal is given by an exponential of a Normal), where the fifteen elements of the
 225 covariance matrix use a numbering reflecting the order of presentation of the mean parameters. With
 226 Bayesian techniques, we do not obtain a standard error for individual parameters that would be suited
 227 for calculating t-ratios, but instead report the posterior standard deviation for each parameter. As
 228 expected, the relative variation in the posteriors is larger for MCT1 than CT1, given the lower sample
 229 size for the former.

230 As a next step, we produced VTT measures on the basis of Table 2. The lognormal has a very
 231 long tail, and a few outlying values can lead to extreme means (see e.g. [16]). With this in mind, we
 232 censored the distributions by removing the 1% of highest values of the WTP distributions. Censoring
 233 is a controversial process but is required in some cases (cf. [17]). It is however crucial to ensure that it
 234 leads to a distribution that still represents the behaviour in the data. We thus used the censored
 235 distributions to recalculate the log-likelihood of the model. For CT1, this led to a minor drop in log-
 236 likelihood to -3473.41 (i.e. a drop of 0.73 units), showing very little support in the data for extreme
 237 values – i.e. the tail is driven by the overall shape of the distribution rather than the data. For MCT1,
 238 there was also only a small drop to -319.34, i.e. by 1.19 units. More extreme censoring quickly led to
 239 substantial drops in fit, suggesting that there is support in the data for the tail of the distribution up to
 240 the 99% point. The censoring led to much more realistic VTT measures, e.g. the final weighted mean
 241 for CT1 travel time is 47c/min, compared to 75c/min.

242 **Table 3: Implied in vehicle value of time measures for car and motorcycle (means and**
 243 **standard deviations across the sample)**

VTTS (cents/mins)	CAR			MOTORCYCLE		
	Mean	std. dev.	Mean as fraction of wage rate	Mean	std. dev.	Mean as fraction of wage rate
value of free flow time vs ERP (c/min)	34.32	71.13	0.69	21.20	25.85	0.74
value of light congestion time vs ERP	36.58	73.19	0.74	24.91	26.14	0.87
value of heavy congestion time vs ERP	46.38	86.71	0.94	24.92	26.14	0.87
value of free flow vs petrol costs	52.63	120.60	1.06	23.86	51.02	0.83
value of light congestion time vs petrol costs	61.52	141.14	1.24	27.72	53.33	0.97
value of heavy congestion time vs petrol costs	90.64	223.60	1.83	27.73	53.34	0.97
value of free flow vs parking costs	54.93	139.73	1.11	38.52	108.98	1.34
value of light congestion time vs parking costs	62.78	156.91	1.27	44.03	114.40	1.53
value of heavy congestion time vs parking costs	89.99	233.25	1.82	44.04	114.42	1.54
value of free flow time vs weighted costs	42.48	92.35	0.86	19.73	30.60	0.69
value of light congestion time vs weighted costs	47.35	99.92	0.96	22.92	31.53	0.80
value of heavy congestion time vs weighted costs	65.49	137.33	1.32	22.93	31.53	0.80
value of weighted travel time vs ERP	36.80	73.60	0.74	23.02	26.00	0.80
value of weighted travel time vs petrol costs	61.00	139.40	1.23	25.75	52.14	0.90
value of weighted travel time vs parking costs	62.52	156.11	1.26	41.22	111.58	1.44
value of time, weighted by conditions and cost components	47.36	99.86	0.96	21.29	31.04	0.74
wage rate from sample (SGD/hr)	29.66			17.21		

244 A wide range of valuations can be calculated from the estimates, as reported in Table 3, including the
 245 VTT against a weighted cost component (calculated at the level of each individual based on their split
 246 in cost components) and the VTT in average travel conditions, calculated for each individual based on
 247 their split in travel components observed in the data. With the individual components now all
 248 following imperfectly correlated random distributions, the individual mean values cannot be obtained
 249 simply as ratios of other means. Additionally, the relative VTT in different travel conditions is not

250 constant across the three cost components as a result of the heterogeneity in each component. Finally,
 251 with a random coefficients model, it is also not appropriate to now calculate simple congestion
 252 multipliers.

253 We note that the differences across congestion levels is stronger for car, where the lack of
 254 difference between light congestion and heavy congestion for motorcycles could reflect that
 255 congestion for overall traffic has a reduced impact on motorcyclists. The sensitivity is highest to ERP,
 256 followed by petrol costs and then parking costs, where the latter is especially low for motorcycle
 257 users. Overall valuations are in general below the wage rate from the estimation sample, where
 258 exceptions arise in relation to petrol and parking costs, potentially suggesting that respondents did not
 259 react to these attributes in a meaningful manner. This finding is in line with some empirical evidence
 260 in other studies, showing that respondents do not react realistically to petrol costs in journey based
 261 choice experiments.

262 After model estimation, we produced posterior distributions, and used the conditional means
 263 for further analysis, where we focus on the valuations against ERP. In Table 4, we report only those
 264 socio-demographics where a meaningful effect was observed. For car, there is clear evidence to
 265 suggest higher VTT measures for home based work travel and non-home based travel, and an
 266 indication of higher VTT for those who obtain compensation for their travel costs. For both modes,
 267 the values are highest for those in employment, and are also higher for off-peak travel than off-peak,
 268 potentially suggesting some self-selection of higher VTT people into the off-peak periods. No clear
 269 patterns could be observed in terms of income or group size effects for either mode.

270 **4.2. Summary results for other non-accident games**

271 We now proceed with a summary discussion of the results for the other non-accident games, with
 272 results in Table 5. Except where otherwise noted, we relied on positive lognormal distributions for
 273 WTP measures and negative lognormal distributions for cost. Except for the different approach in
 274 BT2, we always applied a 1% censoring to the lognormal tails. This led to minor drops in fit for BT1
 275 (3.5 units) and MT1 (0.43 units) and small gains in fit for CT2 (0.15 units), TT1 (0.53 units) and
 276 MT2/PT1 (5.92 units). Overall, these results confirm little empirical support for the extreme values
 277 and justify our censoring approach.

278 *4.2.1. Car out of vehicle time game (CT2)*

279 Respondents are on average most sensitivity to searching time, ahead of walking time and queueing
 280 time, where no constraints on the ordering were imposed. The actual valuations are lower than those
 281 obtained in CT1, where a possible reason could be that out of vehicle times are on average much
 282 shorter (11.8 minutes) than in vehicle times (27 minutes) in our sample. There is substantial empirical
 283 evidence elsewhere to support the notion that VTT measures are higher on longer journeys (e.g. [2]).

284 *4.2.2. Taxi game (TT1)*

285 For TT1, a Normal distribution was used for the constant for booked taxi services, and no constraints
 286 on ordering were imposed. Respondents are on average most sensitive to waiting time, with no
 287 difference between in vehicle time and walking time in the mean, although the latter has a higher
 288 standard deviation. Walking time is on average much shorter than in vehicle time in this sample (1.8
 289 minutes vs 22.6 minutes) and the finding could thus relate to a lower value of small time savings. The
 290 actual valuations are higher than the wage rate, but this needs to be placed into the context of taxi
 291 journeys being infrequent, and travellers being willing to pay for that service, i.e. we can again link
 292 the values to self-selection. As an aside, there is little difference in sensitivities to booking fees and
 293 fares.

294 *4.2.3. Core bus and MRT games (BT1 and MT1)*

295 For BT1 and MT1, the five in vehicle VTT measures were specified in an additive manner, thus
 296 imposing an ordering. Alongside the valuations of out of vehicle time and the five different in vehicle
 297 time valuations, we also calculated a weighted valuations, using the average real world mix of
 298 crowding conditions in the time period a given traveller uses. We find that walking time is valued
 299 more highly than waiting time, especially for MRT. It is also valued more highly than seated travel
 300 time for both modes, and the valuation is only exceeded by both valuations of standing time for bus,
 301 and the valuation of standing in packed conditions for MRT. For both modes, the monetary valuation
 302 of an interchange is over three times as high as the valuation of one minute of travel time in average

303 conditions. For bus, there is essentially no difference in valuation across the two lowest levels of
 304 crowding, where this extends to all three seated levels for MRT. For bus, the valuation in standing
 305 conditions is relatively similar across both levels of crowding, while, for MRT, completely packed
 306 conditions are valued substantially more negatively.
 307

Table 4: Posterior analysis for in vehicle value of time measures for CT1 and MCT1

CT1	Sample size	Value of free flow time vs ERP (c/min)	Value of light congestion time vs ERP (c/min)	Value of heavy congestion time vs ERP (c/min)	Value of weighted travel time vs ERP (c/min)
No purpose	4	27.86	30.65	43.02	30.91
HBO	352	34.34	36.46	45.72	36.68
HBS	171	29.88	31.70	39.74	31.92
HBW	327	37.29	39.84	50.68	40.04
NHB	338	37.01	39.48	49.98	39.68
Work FT, PT or SE	737	36.88	39.35	49.92	39.55
housewife	139	31.15	32.97	41.02	33.20
student	165	32.76	34.75	43.45	34.96
retired	37	35.63	38.38	50.13	38.73
unemployed or work NA	114	33.14	35.17	43.94	35.37
AM PEAK	454	34.66	36.92	46.62	37.12
PM PEAK	293	34.38	36.62	46.22	36.84
Combined PEAK	747	34.55	36.80	46.46	37.01
Off PEAK	445	36.40	38.78	49.04	38.99
Not compensated	1141	34.93	37.22	47.07	37.43
Fully or partly compensated	51	42.30	44.78	55.41	44.95
MCT1	Sample size	Value of free flow time vs ERP (c/min)	Value of light congestion time vs ERP (c/min)	Value of heavy congestion time vs ERP (c/min)	Value of weighted travel time vs ERP (c/min)
No purpose	0	N/A	N/A	N/A	N/A
HBO	18	21.53	25.12	25.13	23.28
HBS	0	N/A	N/A	N/A	N/A
HBW	57	23.25	26.96	26.96	25.07
NHB	32	19.50	23.29	23.30	21.36
Work FT, PT or SE	96	22.92	26.65	26.66	24.75
housewife	3	12.22	15.60	15.61	13.87
student	3	19.12	23.00	23.01	21.02
retired	2	6.74	9.98	9.98	8.33
unemployed or work NA	3	9.71	13.12	13.13	11.38
AM PEAK	45	20.53	24.25	24.26	22.36
PM PEAK	24	18.55	22.20	22.21	20.33
Combined PEAK	69	19.84	23.54	23.54	21.65
Off PEAK	38	25.47	29.21	29.22	27.31
Not compensated	96	22.14	25.84	25.85	23.95
Fully or partly compensated	11	19.26	23.03	23.04	21.11

308 4.2.4. Bus EWT game (BT2)

309 The ranges of EWT presented in the experiment were by definition very narrow, with a maximum and
 310 minimum time in between bus arrival times of 4 and 16 minutes, respectively, leading to a maximum
 311 EWT of just 1.35 minutes, with an average of 0.66 minutes. With a simple two attribute choice, we
 312 can calculate boundary valuations for EWT, and these ranged from 7.69c/min to 4,800c/min. This
 313 would be the valuation of EWT a respondent would need to have to choose the more expensive option
 314 (with a lower EWT) in a given choice task. The median accepted boundary was 75c/min, while the
 315 median rejected boundary was 160c/min, with respective means of 114.87c/min and 374.05c/min.

316 For the valuation of EWT, a different censoring approach was used, based on the work of
 317 [17], censoring the lognormal distribution at the highest accepted boundary value, which was
 318 800c/min. This led to a drop in log-likelihood by 58.65 units which corresponds to 1.9% and is a
 319 much bigger drop than in other games, but was needed in order to obtain reasonable results. The
 320 resulting average valuation of EWT is 71.74c/min, which is in line with the median accepted trade-
 321 off. This is much higher than valuations of in vehicle time from BT1, and exceeds the average wage
 322 rate by a factor of more than two. However, it needs to be borne in mind that achieving a minute
 323 reduction in EWT is a far bigger step than a one minute reduction in travel time.

324 4.2.5. Walking games (MT2 and PT1)

325 For the joint MT2 and PT1 model, we used a Normal distribution for the crossing type constants, and
 326 no constraints were imposed on the ordering of the three time components. The model allowed for
 327 scale differences between MT2 and PT1, where the estimated scale for PT1 is 2.36 (compared to a
 328 MT2 base of 1), showing more deterministic choices in PT1. We note that the valuation of uncovered
 329 walking time is lower than the valuation of walking time from MT1, possibly due to the inclusion of
 330 the PT1 data. Uncovered walking time is valued much more highly than covered walking time, with
 331 crossing time in between, and, with air conditioned underpass being the base, there is on average a
 332 positive willingness to pay for avoiding any of the other crossing types, especially uncovered bridges.

333 4.3. Summary results for accident games

334 For accident games, we focus on the car and pedestrian models due to very small sample sizes for the
 335 motorcycle and cyclist games. We made use of a negative lognormal distribution for tax increases,
 336 along with a positive lognormal distribution for tax reductions, and positive lognormals for the WTP
 337 for reductions in accidents (vs tax increases). The 1% censoring of the Lognormal distributions led to
 338 drops in log-likelihood by 3.26 units (0.16%) for CA1 and 2.09 units (0.24%) for PTA1. The resulting
 339 monetary valuations are presented in Table 6. For each of the three levels of severity, the average
 340 willingness to pay measure is higher in the pedestrian sample than in the car sample. Despite
 341 differences in socio-demographics, this is to be expected at least for fatalities, where the presented
 342 risk was twice as high in the pedestrian sample than the car respondent sample (at average distances).

343 Along with the willingness-to-pay measures coming out of the models, we present the implied
 344 values of risk reduction (calculated as willingness to pay divided by risk), using actual driving
 345 distance for car, and the presented risks from the survey for pedestrians, where no reliable distance
 346 estimate was available from respondents.

347 5. RECOMMENDED VALUES

348 5.1. Main valuations

349 Table 7 presents an overview of the key recommended valuations from the various games,
 350 where, for car and motorcycle in vehicle time, we rely solely on valuations against ERP. An equity
 351 value of travel time was also calculated by using the values of in vehicle time by mode weighted by
 352 travel conditions and by the island wide daily mode share estimated from the 2012 HTS model, giving
 353 a VTT of 27.32 cents per minute or \$16.39 per hour. This equity value has increased from 18.11 cents
 354 per minute in 2008, i.e. an increase by 51%, compared to a GDP per capita growth by just 29%. The
 355 higher VTT could be due to the increase of traffic congestion on the road network, and of passenger
 356 crowding on the public transport system, where improved survey and modelling methodology can
 357 also have affected the values.

358

359

360

Table 5: Summary valuations for non-accident games other than CT1 and MCT1

CT2	Mean	std. dev.	Mean as fraction of wage rate
value of walking time (c/min)	36.39	142.66	0.74
value of queueing time (c/min)	32.62	132.12	0.66
value of searching time (c/min)	40.02	186.07	0.81
TT1	Mean	std. dev.	Mean as fraction of wage rate
value of walking time (c/min)	54.97	102.89	1.28
value of in vehicle time (c/min)	55.27	85.34	1.28
value of waiting time (c/min)	61.59	133.90	1.43
BT1	Mean	std. dev.	Mean as fraction of wage rate
value of walking time (c/min)	15.96	30.76	0.53
value of waiting time (c/min)	15.06	34.85	0.50
value of interchanges (c/interchange)	40.82	122.89	N/A
value of in vehicle time, seated with empty seats (c/min)	10.67	25.34	0.35
value of in vehicle time, seated, quite packed (c/min)	10.88	25.42	0.36
value of in vehicle time, seated, completely packed (c/min)	13.01	25.60	0.43
value of in vehicle time, standing, quite packed (c/min)	16.55	30.38	0.55
value of in vehicle time, standing, completely packed (c/min)	17.01	30.66	0.56
value of vehicle time weighted by crowding conditions (c/min)	11.73	25.39	0.39
MT1	Mean	std. dev.	Mean as fraction of wage rate
value of walking time (c/min)	22.83	46.67	0.67
value of waiting time (c/min)	17.00	32.91	0.50
value of interchanges (c/interchange)	68.16	287.24	N/A
value of in vehicle time, seated with empty seats (c/min)	17.39	43.20	0.51
value of in vehicle time, seated, quite packed (c/min)	17.78	43.39	0.52
value of in vehicle time, seated, completely packed (c/min)	18.01	43.44	0.53
value of in vehicle time, standing, quite packed (c/min)	22.08	48.39	0.65
value of in vehicle time, standing, completely packed (c/min)	24.50	50.40	0.72
value of vehicle time weighted by crowding conditions (c/min)	20.71	46.21	0.61
BT2	Mean	std. dev.	Mean as fraction of wage rate
value of EWT (c/min)	71.74	144.75	2.38
MT2&PT1 combined	Mean	std. dev.	Mean as fraction of wage rate
value of uncovered walking time (c/min)	15.47	27.43	0.51
value of covered walking time (c/min)	5.71	10.93	0.19
value of crossing time (c/min)	10.79	22.73	0.36
WTP for avoiding covered bridge with lift vs air conditioned underpass (c/crossing)	13.56	16.74	N/A
WTP for avoiding covered bridge without lift vs air conditioned underpass (c/crossing)	24.68	40.44	N/A
WTP for avoiding uncovered bridge without lift vs air conditioned underpass (c/crossing)	52.11	45.27	N/A
willingness to pay for avoiding road crossing vs air conditioned underpass (c/crossing)	13.96	20.60	N/A

361

362 **Table 6: Implied WTP values for accident games**

	CA1		PTA1		
	mean	std dev	Mean	std dev	
value of reducing fatalities (SGD/fatality)	95.48	357.67	158.08	626.70	
value of reducing serious injuries (SGD/injury)	3.17	7.79	6.56	16.77	
value of reducing slight injuries (SGD/injury)	0.17	0.40	0.67	2.77	
Risks	risk at 20,000km/year		risk at 500km/year		
Fatality	1/40,000		1/20,000		
serious injury	1/5,000		1/10,000		
slight injury	1/300		1/1,000		
Implied value of risk reduction	using average reported distance (18,850km)		at presented risks (500km/year)		
implied mean value of risk reduction per fatality (SGD/fatality)	4,052,123.50		3,161,602.00		
implied mean value of risk reduction per serious injury (SGD/injury)	16,808.39		65,553.68		
implied mean value of risk reduction per slight injury (SGD/injury)	52.68		674.20		
Recommended values and international comparison					
Type of injury	Singapore		Australia ³	UK ⁴	US ⁵
	(\$2015)	(\$2008)	(\$2007)	(\$2014)	(\$2015)
Fatality	4,052,124	1,874,000	6,579,854	3,580,305	12,690,000
Serious injury	526,776	243,600	320,532	402,326	1,332,450
Slight injury	40,521	18,740	17,098	31,015	38,070

363

364 **5.2. Values of risk reduction**

365 In terms of recommended value of risk reduction (VRR) for different types of accident, we believe
366 that those coming out of CA1 are more realistic, largely also because of a more accurate estimate of
367 the exposure risk. This would lead to a value of risk reduction for a fatality of SGD 4,052,123.50.
368 However, the corresponding values for serious and light injuries (SGD 16,808.39 and SGD 52.68) are
369 very low, possibly suggesting that respondents were focussed on the number of fatalities. Ratios of
370 13% (for serious injury) and 1% for light injury were obtained from [18], and applied to the VRR for
371 fatalities to derive the VRR for serious and slight injuries respectively. This leads to the results at the
372 bottom of Table 6, which also shows a comparison against 2008 and values from other developed
373 countries. While the US value is on the upper range and the 2008 Singapore value is on the lower
374 side, overall, the recommended VRR for Singapore are sensible and within an accepted range.

375 **6. CONCLUSIONS**

376 This paper has summarised the work carried out to update a large number of WTP measures used in
377 transport policy and infrastructure scheme appraisal in Singapore. The work made use of a
378 distinctively large sample (relative to the population) and covered a wide variety of modes and
379 variables. The work also pushed the methodological boundaries by using Mixed Logit models with a
380 full specification of heterogeneity.

381 The values coming out of the analysis are in line with expectation in terms of relationships across
382 modes (showing evidence of self selection) as well as across journey components (e.g. effects of

³ cf. [19]

⁴ cf. [20]

⁵ cf. [21]

383 crowding/congestion). Insights can be gained into differences across modes in terms of the
 384 relationship between congestion levels (e.g. bigger effect for car than motorcycle) and crowding
 385 (bigger effect for bus than MRT).

386 **Table 7: Recommended values across modes**

	CAR	MOTORCYCLE
value of free flow time vs ERP (c/min)	34.32	21.20
value of light congestion time vs ERP (c/min)	36.58	24.91
value of heavy congestion time vs ERP (c/min)	46.38	24.92
value of weighted travel time vs ERP (c/min)	36.80	23.02
value of walking time vs parking cost (c/min)	36.39	-
value of queueing time vs parking cost (c/min)	32.62	-
value of searching time vs parking cost (c/min)	40.02	-
	TAXI	
value of walking time vs fare (c/min)	54.97	
value of in vehicle time vs fare (c/min)	55.27	
value of waiting time vs fare (c/min)	61.59	
	BUS	MRT
value of walking time (c/min)	15.96	22.83
value of waiting time (c/min)	15.06	17.00
value of interchanges (c/interchange)	40.82	68.16
value of in vehicle time, seated with empty seats (c/min)	10.67	17.39
value of in vehicle time, seated, quite packed (c/min)	10.88	17.78
value of in vehicle time, seated, completely packed (c/min)	13.01	18.01
value of in vehicle time, standing, quite packed (c/min)	16.55	22.08
value of in vehicle time, standing, completely packed (c/min)	17.01	24.50
value of in vehicle time weighted by crowding conditions (c/min)	11.73	20.71
value of EWT (c/min)	71.74	
	WALKING	
value of uncovered walking time (c/min)	15.47	
value of covered walking time (c/min)	5.71	
value of crossing time (c/min)	10.79	
WTP for avoiding covered bridge with lift vs air conditioned underpass (c/crossing)	13.56	
WTP for avoiding covered bridge without lift vs air conditioned underpass (c/crossing)	24.68	
WTP for avoiding uncovered bridge without lift vs air conditioned underpass (c/crossing)	52.11	
WTP for avoiding road crossing vs air conditioned underpass (c/crossing)	13.96	

387
 388 Our work uncovered extensive amounts of random heterogeneity in valuations across respondents,
 389 showing clear advantages over models assuming homogeneous preferences. Interestingly, it was not
 390 possible to link much of this to observed respondent characteristics, though some insights were gained
 391 from posterior analysis. This suggests that, at least with this sample, much of the heterogeneity relates
 392 to intrinsic preferences rather than differences in socio-demographics. In this context, the

393 representativeness of the sample is of crucial importance, but with the use of posterior estimates, the
 394 possibility of course also remains open for reweighting of results.

395 The valuations are overall substantially higher than those from the 2008 study. While some of
 396 this can be attributed to changes in the transport system and increased congestion/crowding, the use of
 397 more advanced survey design and modelling approaches may also play a role. This update is thus of
 398 high importance to ensure continued reliability of the cost benefit appraisal work conducted by LTA.
 399 Our work also uncovered differences in VTT measures depending on which cost attribute is used (e.g.
 400 ERP vs petrol) and we recommend to base the core values for car and motorcycle on ERP.

401 Finally, our work has put forward a different approach for SC surveys for safety, and
 402 especially in the context of small areas with low numbers of fatalities, the approach seems preferable
 403 to a route based approach.

404

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410

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