Estimating the Passenger Cost of Station Crowding

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1. Introduction

Significant crowding makes time spent waiting and moving in rail stations less pleasant. Major Sydney rail stations: Town Hall, Wynyard and North Sydney experience platform and accessway crowding particularly in the PM peak when passengers wait for trains. Moreover, demand projections suggest that passenger conditions are likely to worsen in the future. However, catering for the increase in demand by enlarging the effective space for passengers will be difficult and expensive.

Quantifying the passenger cost of increased crowding or the benefits of increased space requires assumptions on how passengers' value time under different levels of crowding. How much would a passenger waiting for five minutes on a platform be 'willing to pay' if crowding density was halved from two passengers per square metre (PSM) to one PSM? Does the cost of crowding vary on platforms to accessways? Is the cost of crowding linear or does crowding add cost only when passenger densities exceed a certain density such as one PSM? Do passengers prefer some other passengers around them rather than waiting on empty or near empty platforms?

Unfortunately, most empirical studies of crowding have focussed on train crowding as opposed to station crowding. The UK Passenger Demand Forecasting Handbook, PDFC (1999) for example tabulates sitting and standing values of travel time that increase with average train load (passengers/train). However, similar values for station crowding are not presented in the Handbook. Although London Underground Operations Research Unit has developed passenger time values under different levels of crowding levels (see section 4) the values are based on judgement rather than being based on surveys of underground users.

To develop some understanding of how Sydney rail users value station crowding, RailCorp NSW undertook a Stated Preference survey of passengers in 2003. The aim of the survey was to derive crowding costs for time spent on platform, access-way and entrance station areas under low, medium and high crowding situations. This paper summarises the survey approach (Section 2) and results (Section 3). Section 4 fits the survey results into a formula developed by London Underground which expresses crowding cost as a function of passenger density. A simple example of increased platform area is used in Section 5 to illustrate how the formula can be used to evaluate the passenger benefits of reduced crowding. Some concluding remarks are made in section 6.

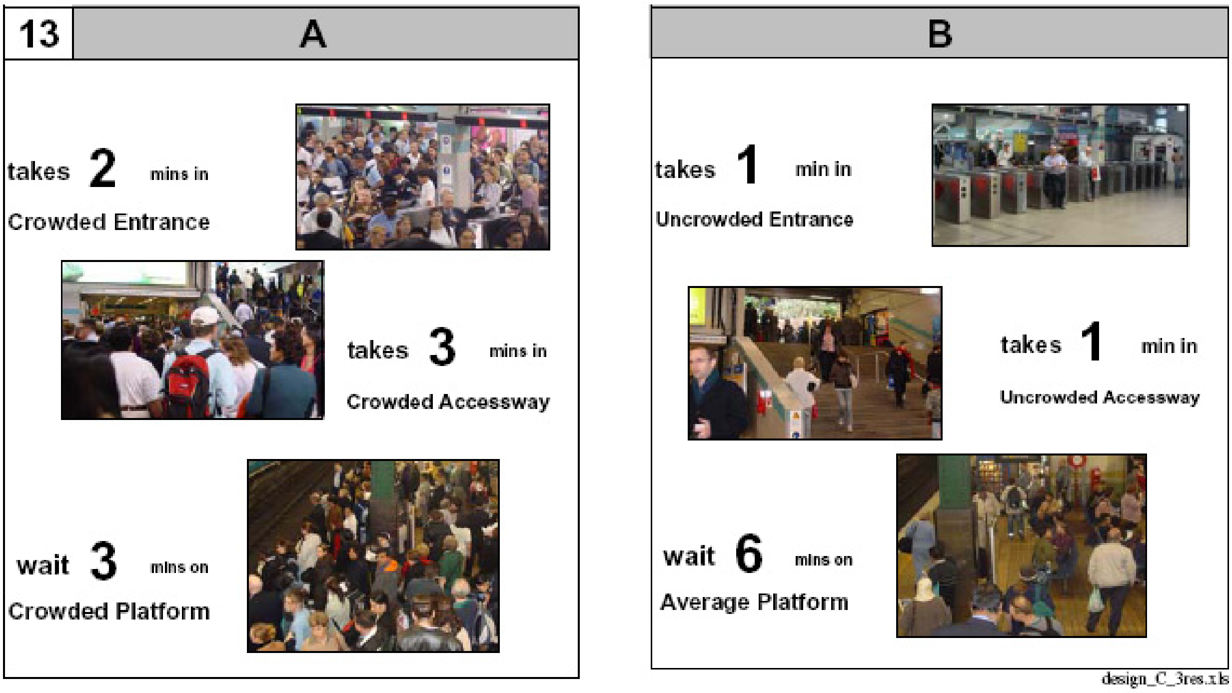
2. Survey Approach

2.1 Survey Design

The core of the survey was a set of Stated Preference (SP) questions in which respondents were asked to choose between two hypothetical journeys that differed in terms of the time spent in different station areas and the level of crowding. Respondents were asked to make their choice in context of the trip they were making. Each respondent undertook nine comparisons. Photographs were used to present the station area and crowding levels.

Figure 1 presents one example SP choice. Option A involved two minutes spent in a crowded entrance, three minutes in a crowded accessway and three minutes waiting on a crowded platform. Option B involved one minute spent in an uncrowded entrance, one minute in an uncrowded accessway and six minutes waiting on an average occupancy platform. Interviewers explained the choices to the respondents and asked which option they would prefer to use.

Figure 1: Example of Stated Preference Question



Note: A and B when shown to respondents were larger (A4 size)

Eighteen choices similar to Figure 1 were developed. The times and crowding were varied in a systematic way so that the effect of crowding level and station area could be established. Three ‘levels’ were used which specified as differences between option A and B. For platform waiting time, the three levels were: (1) Option A 3 mins versus Option B 8 mins; (2) Option A 3 mins versus Option B 6 mins and (3) Option A 2 mins versus Option B 9 mins.

Thus option A had shorter platform times than option B but longer accessway and entrance times. The design therefore embedded a ‘trade-off’ between platform and accessway-entrance time.

The trade-off in station area times was confounded by three levels of crowding, high crowding, medium occupancy and low occupancy. Crowding was also specified as differences (1): Option A high crowding versus Option B medium occupancy; (2) Option A medium occupancy versus Option B high crowding and (3) Option A high crowding versus Option B low occupancy. Different crowding combinations were used for the entrance and accessway areas with photographs used to show the level of crowding.

The full design required eighteen choices. Some questions were ‘reversed’ by swapping the levels of options A and B to make the design less transparent. The experimental design order was also randomised. The design was split into two sets of nine choices to avoid interviewee fatigue with each respondent undertaking one set of nine questions. Interviewers used a tally sheet to record the set undertaken to ensure equal numbers of the sets were obtained overall.

The questionnaire was tested by computer simulation. Response was generated to test whether the experimental design was able to "return" reasonable parameters values and whether the attribute importance was balanced (i.e. one attribute was not dominant). Two pilot surveys were then undertaken to assess the survey instrument. Refinements were made to the experimental design and also to the format of the questionnaire.

2.2 Sample Size and Descriptive Analysis

The main survey was undertaken in July and August 2003. 335 interviews were undertaken. Passengers were interviewed "on train" on a selection of services. Most interviews were undertaken during the AM peak (0600-0930) and PM peak (1530-1830). A set of questions were asked regarding stations used, trip purpose, gender, age, occupation and job. These questions enabled the profile of the sample to be assessed. Interviewers also recorded data about the train service, time and date of survey.

The 335 interviews produced 3,011 SP responses (approx 9x335). The response to the SP questions was well balanced with roughly equal response to the 18 questions.

The survey was reasonably representative when compared with the Sydney rail market. Females were however over-represented in the sample with 195 out of 328 (59%) female and 133 (41%) male. This ratio compared with 51% female and 49% male for the rail population as a whole. Gender weights were applied to the response to take account of differences in crowding valuation amongst males and females (see section 3).

The response to the SP questions slightly favoured option B which featured longer platform waits but shorter accessway and entrance times. Overall, 45% chose A and 55% B.

None of the SP questions produced a unanimous preference for option A or B; the percentage choosing option A ranging from 14% to 83%. For the choice situation shown in Figure 1, 22% chose option A and 78% option B. Over all 18 choices, only seven respondents were unable to decide between A and B. These responses were treated as a 'vote' for both options with each of the two votes weighted by 0.5.

The design was successful in getting respondents to vary their response through the nine questions. 314 out of 335 respondents (94%) varied their response. Of the 21 respondents who did not vary their response, eight (2%) chose option A and thirteen (4%) option B.

2.3 Model Estimation

A logit model, estimated by maximum likelihood, was used to derive the relative importance respondents placed on time spent in each of the three station areas under different levels of crowding. Three variables were computed to express the difference in time spent (A - B) in each station area. In equation 1, T denotes the time spent with E denoting the entrance area. Thus the difference spent in the entrance area for SP question i (ETi) was:

$$ETi = ET_{Ai} - ET_{Bi} \qquad .....(1)$$

where *ETi* = Difference in time spent in station Entrance area for SP choice situation i
A and *B* denote package A and package B respectively

The 'qualitative' nature of crowding was addressed by using dummy (0,1) variables for each station area. A medium occupancy dummy variable and a high crowding dummy variable were created. The medium crowding dummy variable took a value 1 for option A (M_A) if the area for was medium occupancy <u>or</u> high crowding. If the area was low occupancy, the variable was 0. The high crowding dummy variable (H_A) took a value of 1 if high crowding else zero.

The crowding dummy variables were multiplied with the time spent in each area. A difference variable was then created which subtracted A from B for the six time - crowding variables. For the entrance area, the medium and high crowding variables were specified as:

$$ETMi = [ET_{Ai}.M_{Ai}] - [ET_{Bi}.M_{Bi}]$$
$$ETHi = [ET_{Ai}.H_{Ai}] - [ET_{Bi}.H_{Bi}] \quad \text{.....(2)}$$

Where:
ETMi = Difference in entrance area time (minutes) under medium occupancy conditions for SPi
ETHi = Difference in time in entrance area time (minutes) under high crowding for SPi

A linear "utility" function (U) catered for differences in valuation to time and crowding through a set of β parameters. The formulation allowed respondents to prefer medium to low occupancy conditions for example:

$$U_i = \beta_{ET} ET_i + \beta_{ETM}.ETM_i + \beta_{ETH}.ETH_i + \beta_{AT} AT_i + \beta_{ATM} ATM_i + \beta_{ATM} ATH_i + \beta_{PT} PT_i + \beta_{PTM}.PTM_i + \beta_{PTH}.PTH_i \quad \text{.....(3)}$$

Where:
Ui = difference in utility (option A – option B) for SP choice situation i
ETi = Time in Entrance area (mins) under Low crowding
ETMi = Time in Entrance area (mins) under Medium crowding
ETHi = Time in Entrance area (mins) under High crowding
ATi = Time in Accessway (mins) under Low crowding
ATMi = Time in Accessway (mins) under Medium crowding
ATHi = Time in Accessway (mins) under High crowding
PTi = Time on Platform area (mins) under Low crowding
PTMi = Time on Platform (mins) under Medium crowding
PTHi = Time on Platform (mins) under High crowding
β = parameter to be estimated

A simple logit model was fitted to the observed SP choices by maximum likelihood. The estimation equation included a design constant (βo) which theoretically should be zero since if all attribute levels for options A and B were equal respondents should be indifferent. However, the embedded platform versus accessway-entrance area time trade-off meant that the estimated constant could differ significantly from zero if the design levels were set in such a way as to produce a consistent underlying preference for one option (which could not be attributed to the variation in time or crowding level).

$$P_{Ai} = \frac{1}{1 + \exp^{-[\beta o + U_i]}} \quad \text{.....(4)}$$

Where:
P_{Ai} = probability of choosing package A for SP choice situation i
βo = SP design constant

Relative valuations were calculated from the ratio of the estimated parameters. For instance, the relative valuation of a minute of platform waiting time spent in low occupancy conditions compared to medium occupancy conditions was β_{PT}/β_{PTM}. Similarly, the ratio of time spent on platforms in high crowding conditions to medium occupancy conditions was β_{PTH}/β_{PTM}.

The medium occupancy and high crowding parameters were added ($\beta_{PTH}+\beta_{PTM}$) to get the full valuation of time spent in high crowding conditions. Thus the relative value of platform time in high crowded conditions to low occupancy conditions was ($\beta_{PTH}+\beta_{PTM}$)/β_{PT}.

The value of time spent in different station areas was also determined by the ratio of the respective parameters. For example, the value of a minute spent in accessways relative to on platforms in low occupancy conditions was β_{AT}/β_{PT}.

The 95% confidence limit (CL) for the relative valuations depended on the value, variance and covariance (where the independent estimators are correlated) of the parameters. The narrower the confidence range, the more precise the estimate:

$$95\%CL = 1.96.\left\{\left[\frac{\beta_1}{\beta_2}\right]^2.\left(\left[\frac{\mathrm{Var}(\beta_1)}{\beta_1^{\,2}}\right]+.\left[\frac{\mathrm{Var}(\beta_2)}{\beta_2^{\,2}}\right]-2.\left[\frac{\mathrm{Cov}[\beta_1,\beta_2]}{\beta_1.\beta_2}\right]\right)\right\}^{\frac{1}{2}} \quad .....(5)$$

Although, the original levels were orthogonal, the interaction between the time in each station area and the level of crowding introduced some correlations. Inter-station area correlations were negligible but some intra station area correlations were present. For the platform area, the correlations were weak but for the entrance and accessway areas, stronger correlations were present which compromised the ability to attribute variation in response to the individual crowding variables.

Table 1: Correlation Matrix

Attribute	Name	PTD	PTCD	PTMD	ETD	ETCD	ETMD	CTD	CTCD	CTMD
Platform Time mins	PTD	**1**	0.14	0.11	0.00	0.00	0.00	0.00	0.08	0.00
Platform Time * High Crowding	PTCD	0.14	**1**	0.16	0.03	-0.03	0.01	-0.03	-0.01	0.05
Platform Time * Medium Crowding	PTMD	0.11	0.16	**1**	-0.09	-0.08	-0.31	0.17	0.03	0.11
Entrance Time	ETD	-0.01	0.30	-0.09	**1**	0.35	0.87	0.00	0.04	0.05
Entrance Time * High Crowding	ETCD	0.00	-0.03	-0.08	0.35	**1**	0.53	-0.03	-0.16	-0.08
Entrance Time * Med.Crowding	ETMD	-0.01	0.01	-0.31	0.87	0.53	**1**	0.00	-0.08	0.06
Accessway Time mins	CTD	0.00	-0.03	0.17	0.00	-0.03	0.00	**1**	0.34	0.85
Accessway Time * High Crowding	CTCD	0.08	-0.01	0.03	-0.04	-0.16	-0.08	0.34	**1**	0.50
Accessway Time * Med. Crowding	CTMD	0.00	0.05	0.11	0.05	-0.08	0.06	0.85	0.50	**1**

stat_lim_1.xls

3. Estimated Models

Table 2 presents the estimated parameters and associated |t| values (a measure of the statistical accuracy of estimate). On theoretical grounds, the model without constant is preferred (see section 2.3).

Respondents were most sensitive to platform time with all three crowding level parameters being significant (|t| > 2). High crowding platform time (βPTH) was the most significant parameter (|t| = 16.35) and was negative implying fewer respondents choose the option, the greater the time spent in high crowded conditions. The medium crowding platform parameter (βPTM) which was positive needs to be considered with the ‘base’ wait parameter (βPT) which was negative and considerably larger. Thus taken together, the two parameters imply respondents preferred waiting on medium occupancy platforms than waiting on low occupancy platforms (the base parameter).

Table 2: Estimated Basic Model

β	Attribute	All Constant	All No Constant
βPT	Platform Time mins	-0.235	-0.157
	|*t*|	*9.50*	*9.06*
βPTH	Platform Time * High Crowding	-0.141	-0.140
	|*t*|	*16.35*	*16.39*
βPTM	Platform Time * Medium Crowding	0.037	0.029
	|*t*|	*3.14*	*2.46*
βET	Entrance Time	-0.033	-0.074
	|*t*|	*0.30*	*0.68*
βETH	Entrance Time * High Crowding	-0.086	-0.089
	|*t*|	*2.62*	*2.71*
βETM	Entrance Time * Med.Crowding	-0.056	-0.132
	|*t*|	*0.50*	*1.19*
βAT	Accessway Time mins	-0.226	-0.232
	|*t*|	*3.40*	*3.51*
βATH	Accessway Time * High Crowding	-0.073	-0.105
	|*t*|	*2.33*	*3.46*
βATM	Accessway Time * Med. Crowding	0.093	0.080
	|*t*|	*1.34*	*1.17*
βo	SP Constant	-0.791	
	|*t*|	*4.44*	
	Rho Squared w.r.t. Zero	0.12	0.12
	SP Responses	3,011	3,011
	SP Interviews	355	355

stat_lim_1.xls

For the station entrance, only high crowded time (βETH) was significant. The parameters for medium occupancy (βETM) and low occupancy (βET) were not significantly different from zero. Parameter significance improved with the constant omitted. The base (βAT)and high crowding (βATH) accessway parameters were significant but the parameter for medium crowding (βATM) was of lower significance (t=1.17). As for platform areas, the medium occupancy parameter was positive (implying a preference for medium to low occupancy conditions).

A significant negative constant was estimated which reflected an underlying preference for option B (longer platform times but shorter accessway-entrance times) worth 3.7 minutes of platform waiting time. Estimating the model without a constant reduced the platform parameters (especially the base parameter) and increased the entrance parameters whilst leaving the accessway parameters largely unchanged.

Separate models were fitted for males and females (Table 3) which showed males to be more sensitive to the length of time than to females whereas females tended to more sensitive to crowding level - disliking high crowding and low occupancy particularly in platform and entrance areas.

Table 3: Estimated Models by Gender

		Constant		No Constant	
β	Attribute	Males	Females	Males	Females
βPT	Platform Time mins	-0.304	-0.185	-0.205	-0.123
	|*t*|	*7.78*	*5.52*	*7.42*	*5.32*
βPTH	Plat.Time * High Crowding	-0.107	-0.186	-0.106	-0.185
	|*t*|	*7.90*	*15.52*	*7.92*	*15.58*
βPTM	Plat. Time * Medium Crowding	0.037	0.044	0.026	0.037
	|*t*|	*2.03*	*2.71*	*1.47*	*2.32*
βET	Entrance Time	-0.164	0.035	-0.211	0.000
	|*t*|	*0.96*	*0.23*	*1.25*	*0.00*
βETH	Ent. Time * High Crowding	-0.095	-0.111	-0.098	-0.113
	|*t*|	*1.83*	*2.48*	*1.90*	*2.53*
βETM	Ent. Time * Med.Crowding	0.105	-0.138	0.001	-0.194
	|*t*|	*0.60*	*0.88*	*0.00*	*1.26*
βAT	Accessway Time mins	-0.276	-0.164	-0.284	-0.166
	|*t*|	*2.71*	*1.77*	*2.81*	*1.80*
βATH	Acc'way Time * High Crowding	-0.068	-0.065	-0.113	-0.088
	|*t*|	*1.39*	*1.54*	*2.39*	*2.12*
βATM	Acc'way Time * Med. Crowding	0.121	0.047	0.108	0.034
	|*t*|	*1.12*	*0.50*	*1.01*	*0.37*
βo	SP Constant	-1.013	-0.618		
	|*t*|	*3.61*	*2.55*		
	Rho Squared w.r.t. Zero	0.10	0.15	0.09	0.15
	SP Responses	1,199	1,754	1,199	1,754
	SP Interviews	133	195	133	195

A final model was fitted in which the parameter values for access and entrance were constrained to equal one another, gender was weighted to match the overall CityRail profile and the medium accessway-entrance crowding level (which had low statistical significance) was omitted.

Table 4: Estimated Final Model

β	Attribute	Parameter Estimate
βPT	Platform Time mins	-0.151
	|*t*|	*9.16*
βPTH	Platform Time * High Crowding	-0.133
	|*t*|	*16.47*
βPTM	Platform Time * Medium Crowding	0.034
	|*t*|	*3.50*
βAET	Access/Entrance Time	-0.173
	|*t*|	*6.81*
βAETH	Access/Entrance Time * High Crowding	-0.096
	|*t*|	*5.06*
	Rho Squared w.r.t. Zero	0.14
	SP Responses	3,011
	SP Interviews	335

The reduced model contained five variables: high crowding platform time (βPTH); medium occupancy platform time (βTM); base platform time (βPT); high crowding accessway-entrance time (βAETH) and base accessway-entrance time (βAE). All five variables had high |t| values ranging from 3.5 for medium occupancy platform time (βPTM) to 16.5 for high crowding platform time (βPTH).

Accessway and entrance time was valued higher than platform waiting time (reflecting the effort of 'moving'), with the difference most marked at medium occupancy conditions, see Figure 2. For low occupancy conditions, a minute of accessway-entrance time was valued

1.15 greater than a minute spent on a platform. The valuation of accessway-entrance time peaked at 1.48 times platform time at medium occupancy conditions. The valuation then returned to 1.08 times platform time for high crowding conditions.

Figure 3 shows the crowding valuations for each station area. A 'U' shaped function was estimated for platforms with a greater time valuation for low as well as high crowding than under medium conditions. For low occupancy conditions, platform time was valued at 1.3 times greater than under medium occupancy conditions. For high crowded conditions, a minute of platform time was valued equal to 2.1 minutes of medium occupancy time.

For accessways and entrances, there was no difference in the valuations for low and medium occupancy conditions. However, time spent in high crowded conditions was valued 1.6 greater higher under medium occupancy conditions.

Figure 2: Station Area Valuations

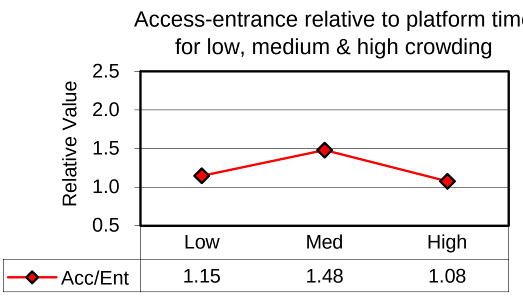


Figure 3: Crowding Valuations

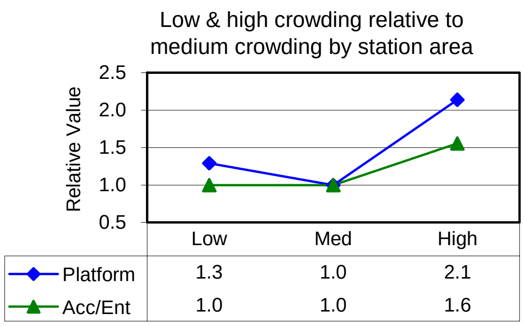


Table 5 presents the 95% confidence range of the relative valuations (expressed relative to medium occupancy platform time). A minute of platform time under high crowding conditions was estimated to range from 1.7 to 2.5 minutes of time under medium occupancy conditions.

Table 5: Range in Estimated Valuations

Station Area	Estimate	High	Medium	Low
	Upper 95% Estimate	2.5	1	1.5
Platform	**Central**	**2.1**	**1**	**1.3**
	Lower 95% Estimate	1.7	1	1.1
	Standard Error	*0.20*	-	*0.12*
	Upper 95% Estimate	3.2	2.1	2.1
Accessway/Entrance	**Central**	**2.3**	**1.5**	**1.5**
	Lower 95% Estimate	1.4	0.8	0.8
	Standard Error	*0.47*	*0.33*	*0.33*

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3.2 Fare Valuation of Station Time

The survey did not estimate money values of time such as the willingness to pay a higher fare to save a minute spent on a platform). It was possible to derive money valuations by reference to similar 'Value of Time' market research undertaken of Sydney rail passengers in 2003-4, Douglas Economics (2004). The 'Value of Time' study estimated platform waiting time to be valued at $14.19 for peak travellers, $11.75 for off-peak travellers and $13.14 per hour for average travellers (peak and off-peak) under medium occupancy assumed conditions.

With these waiting time valuations, an hour of peak period platform waiting would be valued at $30.33 in high crowding conditions (compared to $14.19 in medium conditions). Although presented in Table 6 for completeness, it is unlikely that off-peak travellers would experience high crowding station conditions.

Table 6: Valuation of Station Time in terms of Fare ($/hr)

	Peak Crowding Level			Off-Peak Crowding Level			Average Crowding Level		
Station Area	High	Medium	Low	High	Medium	Low	High	Medium	Low
Platform	30.33	14.19	18.33	25.11	11.75	15.17	28.09	13.14	16.97
Accessway/Entrance	32.65	21.00	21.00	27.03	17.38	17.38	30.24	19.45	19.45

note: the values include GST

4. Development of a Crowding Function

Fruin (1972) and London Underground Limited (LUL), Westin (1993) have developed crowding density measures. Generally, the greater the density, the less pleasant waiting or moving becomes with both studies allowing crowding to affect moving and waiting passengers differently.

Fruin defined six levels of crowding for “queuing areas”, “walkways" and "stairways". The levels are denoted A to F with level A being the most pleasant and F the least pleasant. RailCorp aims to meet level C. For a queuing area, Fruin’s C equates to 1.08 and 1.54 PSM; for a stairway between 0.72 and 1.08 PSM; and, for a walkway between 0.43 and 0.72 PSM. Fruin did not provide any travel time valuations.

LUL research has also looked at the effect of crowding on walking speed (as well as how passengers value time in crowded conditions). It is important to recognise that walking speed and hence the actual time to move is also affected by crowding. As crowding increases, queues develop and speeds drop. This crowding effect (which is not addressed in this paper) is distinct from how passengers value a given minute of time under different crowding conditions.

LUL developed a crowding factor (CF) that inflates the value of time with increasing density. The factor is non-linear, increasing as the square of density. The factor is only effective for densities greater than 0.5 PSM and reaches a maximum of 1.18 at a maximum density of 2 PSM. The crowding factor adds to standard waiting time (valued twice rail in-vehicle time).

$$CF = 0 : PSM \leq 0.5$$
$$CF = 0.524.[PSM - 0.54]^2 : 0.5 \leq PSM \leq 2 \quad \ldots..(6)$$
$$CF = 1.18 : PSM \geq 2$$

LUL has developed weights for waiting, standing and walking time under different levels of crowding. Table 7 presents the LUL weights relative to (i) time spent standing on platforms waiting for trains in uncrowded conditions (PSM $\leq$ 0.5) and (ii) time spent sitting on uncrowded trains. A minute spent waiting is valued the same as a minute spent walking on the flat but twice that of a minute spent sitting comfortably onboard a train. LUL valued a minute of walking time up stairs (or escalators) twice that of waiting time and 1.25 times greater if descending. A minute spent standing on an escalator (or in a lift) was valued at 0.75 minutes of time spent walking (or waiting for a train). The LUL crowding factor (CF) factors the weights for the level of crowding. At a passenger crowding density of 1 PSM, the CF is 1.07 i.e. the value of a minute waiting times increases by 7% (i.e. to 2.14 minutes of on-train (IVT) time). At high crowding with 2 PSM, the value of waiting time increases by 1.59 (i.e. to 3.18 IVT).

Table 7: LUL Travel Time Weights relative to On-Train (sitting) Time

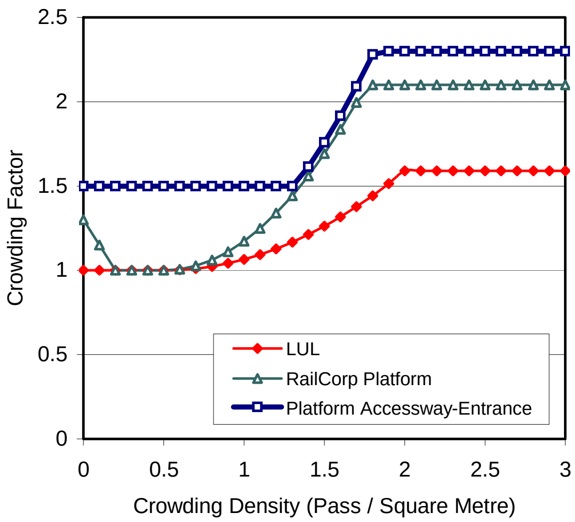
Time Spent	Passenger Density (PSM)	Crowding Factor Relative To: Uncrowded Platform Waiting (PSM ≤ 0.5)	On Train uncrowded sitting
Waiting & Walking	≤0.5	1	2
Waiting & Walking	1	1.07	2.13
Waiting & Walking	2	1.59	3.18
Standing on escalator / in lift	≤0.5	0.75	1.5
Walking up Stairs/Escalators	≤0.5	2	4
Walking down stairs	≤0.5	1.25	2.5

PSM: Pasengers per square metre Source: LUL

The LUL values of time are understood were based on judgement rather than surveys. The RailCorp survey used photographs to represent low, medium and high crowding. Expressing the survey values for low, medium and high crowding in terms of passenger density required assumptions regarding the level of crowding to be made regarding each photograph. The Low occupancy photographs were assumed representative of 0.2 PSM density conditions; the medium occupancy photographs 0.5 PSM and the high crowding photographs 2 PSM. The LUL formula was then used to develop crowding functions for (i) platform and (ii) accessway/entrance time.

As can be seen from Figure 4, the RailCorp survey values are higher than their LUL counterparts. The survey estimated a platform crowding factor (PCF) of 1.3 for waiting time in very low occupancy conditions (PSM ≤ 0.1) and 1.15 for low occupancies (0.1 ≤ PSM ≤ 0.2). The PCF then remains at 1 until a density of 0.5 PSM is reached when it increases to a maximum of 2.1 at 1.8 PSM (based on the ratio of the RailCorp high crowding and maximum LUL factors) as shown in equation 7. For accessways or entrances, a crowding factor (AECF) of 1.5 times medium platform time applies until a density of 0.5 PSM is reached. Then the crowding factor rises according to equation 8 until a maximum crowding factor of 2.3 is reached at 1.9 PSM.

Figure 4: Estimated Crowding Factor for Platform and Accessway-Entrance Time



Passenger PSM	Crowding Factor relative to medium occupancy platform waiting time (0.2 ≤ PSM ≤ 0.5): Platform (PCF)	Accessway-Entrance (AECF)
0.0	1.30	1.50
0.1	1.15	1.50
0.2	1.00	1.50
0.5	1.00	1.50
0.7	1.03	1.50
0.9	1.11	1.50
1.0	1.17	1.50
1.2	1.34	1.50
1.5	1.69	1.76
1.7	2.00	2.09
1.9	2.10	2.30
2.0	2.10	2.30

Equation 7: Platform Crowding Function

$$PCF = 1.30 - 1.5.PSM : PSM \leq 0.2$$
$$PCF = 1 : 0.2 < PSM \leq 0.5$$
$$PCF = 0.692.[PSM - 0.54]^2 : 0.5 \leq PSM \leq 1.8$$
$$PCF = 2.1 : PSM > 1.8$$

Equation 8: Accessway-Entrance Crowding Function

$$AECF = 1.5 : PSM \leq 0.5$$
$$AECF = 0.758.[PSM - 0.54]^2 : 0.5 \leq PSM \leq 1.9$$
$$AECF = 2.3 : PSM > 1.9$$

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5. A Simple Example of Increasing Platform Size

Consider a proposal to increase the size of a platform area from 450 to 500 square metres. The current passenger density for the PM peak half hour (1700-1730) is calculated at one PSM. Each passenger is estimated to wait for five minutes for their train with 2,700 passengers using the platform to board trains during the half hour period.

The total minutes waiting would be 13,500 minutes (2,700 x 5 minutes). To take account of crowding, the appropriate crowding factor for a density of one PSM can be looked up from Figure 4. This is 1.17. The weighted wait time expressed in equivalent medium occupancy minutes is therefore 5.85 minutes per person (5 minutes x 1.17) or 15,795 minutes in total.

With the proposed increase in platform area, the crowding density would fall to 0.9 PSM (450/500 x 1). The new crowding factor (from Figure 4) would be 1.11. The weighted wait time in medium occupancy conditions minutes would reduce to 5.55 minutes per passenger or 14,985 minutes in total.

The proposal therefore produces a benefit of 0.3 minutes per passenger and 810 minutes in total for the thirty minute period (0.3 x 2,700 passengers). With wait time (under medium occupancy conditions) valued at $14.19 per hour by peak travellers (Table 6), the proposal would produce a passenger benefit of 7.095 cents per trip (100 x $14.19/hr ÷ 60 x 0.3 minutes) and $191.565 overall (810 x $14.19/hr ÷ 60) for the thirty minute period.

6. Concluding Remarks

The survey of Sydney rail passengers found that crowding was perceived to increase the value of time spent moving or waiting in stations with high crowding doubling the ‘cost’ of a minute compared to medium occupancy conditions.

There was some evidence for a ‘U’ shaped curve with time spent in low occupancy conditions also valued higher than under medium occupancy conditions particularly amongst female passengers.

Differences in the value of time were also established by station area with accessway and entrance time valued 50% higher than time spent on platforms reflecting the additional effort of moving rather than standing.

The estimated crowding valuations were converted into a continuous measure by reference to a crowding density function developed by London Underground. The resultant crowding function may be used in demand models or in economic evaluations of station improvements.

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