Estimating the Passenger Cost of Train Overcrowding

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The views expressed in this paper are those of the authors and need not be supported by RailCorp.

1. Introduction

Having to stand on trains, especially in cramped conditions makes rail travel a less pleasant experience. Crowded seating also tends to be less pleasant than uncrowded seating.

Population and employment growth exacerbated by recent increases in the price of petrol have increased passenger train loads on Sydney's rail system which have in turn have heightened crowding on peak train services. Moreover, demand projections suggest that future passenger conditions are likely to worsen. On the supply side, catering for increased passenger loads through the purchase of additional rolling stock and by increasing track capacity is likely to be expensive. Therefore, finding the right balance between passenger loads and capacity is an important economic decision.

Quantifying the passenger cost of increased crowding or conversely the benefits of additional train capacity requires assumptions on how passengers' value time under different levels of on-train crowding. How much would a passenger who has to stand for 20 minutes on a train be 'willing to pay' for the comfort of an uncrowded seat? How does the cost of crowding increase if standing is in crushed conditions? Does the cost of standing per minute increase if passengers have to stand for a long periods of time? Is there also a cost of sitting in crowded versus uncrowded seating?

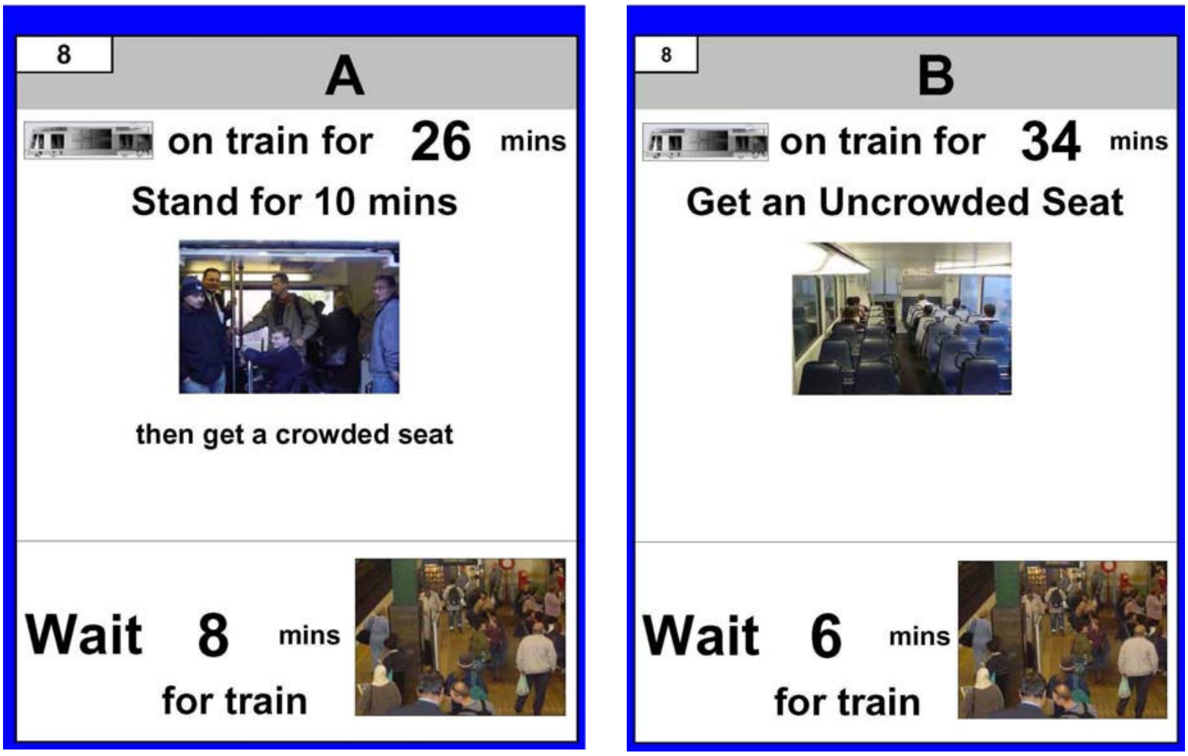
Although there have been some studies undertaken on the cost of crowding overseas for Sydney, the most recent values were established in the mid 1990s, PCIE (1995). To update the Sydney values of on-train crowding, a Stated Preference survey of passengers was undertaken in 2005. This paper summarises the survey approach (Section 2), sample (Section 3) models (Section 4) and results (Section 4). Section 5 reviews the estimated crowding values with earlier Sydney research and UK studies. A simple worked example is then used in Section 6 to illustrate how the formula can be used to evaluate the passenger benefits of reduced crowding. Some concluding remarks are made in section 7.

2. Survey Approach

A similar survey as developed to estimate the cost of station crowding by Douglas and Karpouzis (2005) was used. 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 on-train travel time, waiting time and on-train 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 'show card' 8. You would spend 26 minutes on train A with 10 minutes standing and 16 minutes in crowded seating and you would wait eight minutes for the train. For train B, you would spend 34 minutes on the train in uncrowded seating and wait 6 minutes for the train. So comparing A with B, train A would be 8 minutes quicker in time spent on the train but would involve 10 minutes standing then crowded seating whereas train B would be uncrowded seating. Train A would also involve a 2 minute longer wait for the train. Passengers were asked which train they would use, either train A or train B for the trip then were then making. Respondents who were indifferent between AZ and B were recorded accordingly.

Figure 1: Example of Stated Preference Question



Sixteen choices similar to Figure 1 were developed. The times and crowding were varied in a systematic way so that the effect of travel time and crowding could be established statistically. To do this, four travel attributes were defined in the experimental design: the difference in train waiting time train service A versus train service B; the difference in onboard time for train service A versus train service B; the level of crowding on train A; and the level of crowding on train B.

Each attribute was defined to take one of four 'levels', For waiting time and onboard time, the levels were specified as 'differences' between train services A and B. For level 0, the waiting time train A was seven minutes less than for option B. For attribute level 1, the onboard train time for service A was 4 minutes longer than for service B. Option B was designed to take longer in onboard train time than option A. Offsetting the longer onboard train time for 12 out of 16 choices was a shorter platform wait. Therefore three-quarters of the choices featured a 'trade-off' between onboard train time and wait time.

Train crowding was superimposed on the onboard-waiting time trade-off. The crowding levels were specified separately for services option A and B. Train A was described in terms of three crowding levels: uncrowded seats, crowded seat, stand for 10 minutes (uncrowded seat was featured in levels 0 and 3). Four levels of crowding were specified for train B: crowded seat, stand for 10 minutes, stand for 10 minutes in crush and stand for 20 minutes. Where crowding time was specified, time not spent standing was specified as spent 'in crowded seating'. In general but not always, train B was more crowded than train A. Thus the trade-off passengers were posed was a longer wait for a faster train trip in more crowded conditions.

Photographs were used to standardise the crowding levels. The full design required sixteen 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 eight 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.

3 Sample Size and Descriptive Analysis

The surveys were undertaken between November and December 2005. All surveys were undertaken on platforms as passengers waiting for their trains during the AM and PM peaks. Interviews were conducted at 17 stations where passengers could choose between fast but crowded services and slower but less crowded services were selected. Surburban stations were surveyed in the AM peak and CBD stations in the PM peak.

In total 583 interviews were completed undertaken. 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 survey was reasonably representative when compared with the Sydney rail market. Females were over-represented in the sample however. 337 females were interviewed compared to 213 males. The gender of 33 responses was not recorded.

The female share of 58% compares with a 50:50 CityRail Customer Survey female: male split for the peak. The survey found females to have a significantly higher valuation of crowding than males. Accordingly, weights were applied to bring the sample into line with the CityRail 50:50 split.

A total of 4,603 SP responses were obtained. The number of SPs completed would have been 4,664 if all 334 respondents had answered eight SPs each (8 x 583). The difference was due to a 25 interviews (4.5%) being aborted due to respondents needing to board trains.

The response to the 16 questions was reasonably well balanced. Slightly fewer blue sets (1-8) were interviewed than pink (9-16) and there were responses variations by SP question with higher numbered show cards tending to have lower response than lower numbered show cards (due to interview aborts).

The response to the SP questions slightly favoured option A which involved a shorter wait, less crowding but a longer on-train time. Overall 64% chose option A and 36% option B.

None of the SP questions produced a unanimous preference for option A or B; the percentage choosing option A ranging from 23% to 91%. For experimental design number 11 (show card 8) described in section 3.1, 30% chose option A (a 6 minute wait and a 34 minute onboard train time in an uncrowded seat) with 70% choosing option B (an eight minute wait and 26 minute onboard time with a 10 minute stand).[1]

47 responses were indifferent between option A and B; these responses were treated as a 0.5 probability of choosing A (and B).

The design was successful in getting respondents to vary their preference for slower but less crowded option A versus faster but crowded option B (i.e. experimental design options rather than show card option). Only four respondents did not vary their response with 553 out of 557 (99.3%) respondents (who answered eight questions) varied their preference for experimental design A over B.

4. Model Estimation

A simple logit model was fitted to the observed SP choices by maximum likelihood. The probability of choosing train service A was expressed in terms of the difference in waiting time, on-train travel time and on-train crowding. A logit model was used to keep the predicted probabilities within 0 and 1, equation 1. The model was estimated by maximum likelihood on the individual response data.[2]

$$P_{Ai} = \frac{1}{1 + \exp^{-[\beta o + \Delta U i_i]}} \quad .....(1)$$

P_{Ai} = probability of choosing package A for SP choice situation i
ΔUi = difference in utility (option A – option B) for SP choice situation i
βo = SP design constant

The difference in utility was a function of the waiting time, on-train time and crowding attribute differences (A-B), equation 2 with passenger responsiveness to differences in time and crowding expressed through a set of parameters (β) which were estimated by the model.

$$\Delta U_i = \beta_w.\Delta WAIT_i + \beta_v.\Delta IVT_i + \beta_{cseat}.\Delta CRWDSEAT_i + \beta_{std}.\Delta STD_i + \beta_{std20}.\Delta STD20_i + \beta_{crush}.\Delta CRSH\_STD_i ...(2)$$

Where:
$\Delta WAIT_i$ = Difference in platform wait time (A-B) in minutes for SP choice i
ΔIVT_i = Difference in onboard train time (A-B) in minutes for SP choice i
$\Delta CRWDSEAT_i$ = Difference in crowded seat time (A-B) in minutes for SP choice i
ΔSTD_i = Difference in on-train standing time (A-B) in minutes for SP choice i
$\Delta STD20_i$ = Difference in on-train standing time of 20 minutes (A-B) for SP choice i
$\Delta CRSH\_STD_i$ = Difference in on-train crush standing (A-B) in minutes for SP choice i
$\beta_w, \beta_v, \beta_{cseat}, \beta_{std}, \beta_{std20}, \beta_{crush}$ = parameters to be estimated

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[1] It should be noted that the service levels of A and B were reversed on show card 8, thus the percentage choosing option A shown in Figure 3.1 was 70% with 30% choosing option B.

[2] The data was transformed back from the show cards to that of the experimental design. That is, where A and B were reversed on the show cards, the preference of the respondent was reversed (i.e. if the respondent preferred Show Card A where the levels had been reversed, analysis was based on a preference for B with un reversed levels). This enabled the experimental design levels to be used which were uncorrelated whereas the reversed levels were not).

Although included, the SP design constant (βo) should theoretically be zero since with no difference in travel time and crowding between A and B, respondents should be indifferent between the two options (i.e. the probability of choosing A should be 0.5). As.2 discussed however, the SP design embedded a wait time versus onboard time / crowding trade-off. Thus, the estimated constant could be different from zero if there was an underlying preference for faster on-board train times, wait times or less crowding.

The relative valuation of one attribute over another can be calculated from the ratio of the estimated parameters. For instance, a minute of waiting in equivalent on-train (uncrowded) time minutes would be given by the ration β_w/β_v. Similarly, the ratio of standing time to uncrowded seat time is given by β_{stand}/β_v. The onboard time parameter and stand time parameters need to be added ($\beta_{stand+}\beta_v$) to get the full valuation of onboard train time spent standing.

By design, wait and onboard train time were uncorrelated. However there was some correlation between the crowding attributes as a result of specifying the attributes as differences (A-B) and incremental variables.

5. Estimated Models

The estimated parameters and associated |t| values (a measure of the statistical accuracy of estimate) are presented in Table 1. Weights were applied to take account of over-sampling of females and an imbalance in SP response.

All the travel time and crowding parameters were significant at the 95% confidence level (|t| > 1.96). The |t| values ranged from 5.6 for standing onboard greater than 10 minutes to 14.9 for waiting time.

The SP constant was the least significant parameter with a |t| value of 5.4. Theoretically and ideally however, the constant should not be significantly different from zero.

The positive constant indicated an underlying preference for option A which was unable to be attributed to either the travel time or crowding variables. Option A tended to be longer in onboard travel time, shorter in platform wait and be less crowded than option B. In relative size, the constant was worth 4.3 minutes of onboard travel time (0.69 ÷ 0.161).

The wait time parameter was low in relation to onboard time at 0.93 (βwait (-0.149) ÷βv (-0.161). Conventionally, wait time is valued twice onboard travel time.

Table 1: Estimated Model

Observations weighted by gender & SP question

Parameter	Variable Time difference (A-B) mins	Estimate	|t|
βwait	Platform wait	-0.149	14.9
βv	Onboard train	-0.161	9.3
βcseat	Crowded seat	-0.028	12.0
βstd	Stand onboard	-0.054	8.1
βstd20	Stand onboard > 10 mins	-0.077	5.6
βcrush	Crush stand onboard	-0.114	12.0
βo	Constant	0.690	5.4
Model Fit Details			
Log-L		-2,420	
Log-L(0)		-2,368	
Number of observations		4,603	
Number of SP Interviews		583	

Source: RailCorp Surveys, Douglas Economics Analysis
SydCrowdRes06_1.xls!All

Gender, age, journey purpose models were developed to test for differences in sensitivity to travel time and crowding.

For gender, a dichotomous variable taking a value of 1 if female and 0 if male was multiplied with the travel time and crowding variables. The utility expression, in general form, is shown in equation 3.

$$\Delta U_{ij} = \beta_{fo}.F_j + \sum_k \beta_k.\Delta Xk_i + \beta_{fk}.\Delta Xk_i.F_j \quad .....(3)$$

where:

ΔUi = difference in utility (option A – option B) for SP choice situation i for individual j

β_{fo} = SP design constant for females

ΔX_i = Difference in attribute (A-B) for attribute Xk

β_k = Sensitivity (base) parameter for attribute Xk

F_j = Gender variable taking a value of 1 if respondent i is female else 0

β_{fk} = Additive sensitivity parameter (base parameter) for females for attribute Xk

For age, young (under 20 year olds) and old respondents (65 & over) were distinguished from other aged respondents (20 – 64). For trip purpose, education and other trip purposes were distinguished for commuting to work trips.

Although some differences in sensitivity were estimated as shown in Table 2, only a higher sensitivity to standing onboard for 'other' trips (compared to commuting to work trips) was significant at the 95% confidence level. However this effect became insignificant when the other less significant variables were removed from the estimation equation.

Table 2: Gender, Age & Trip Purpose Effects

	Gender	Age		Trip Purpose	
	Females cf males	Old (65+) cf 21-64	Young (<20) cf 21-64	Other cf work	Education cf work
Platform wait	+			+	
Onboard train	+			+	
Crowded seat		-	+		
Stand onboard	+			++	
Stand onboard > 10 mins			+	-	
Crush stand onboard	+	+	+		
Constant		+	+	+	

Notes: ++ greater sensitivity than base group at 95% confidence level
+ greater sensitivity than base group at 90% confidence level
- reduced sensitivity than base group at 90% confidence level
work = commuting to or from work

Source: RailCorp Surveys, Douglas Economics Analysis SydCrowdRes06_1.xls!SDS

Females tended to be more sensitive than males to the attribute differences. Removing the less significant effects increased the significance of crush standing onboard which left females to be 50% more sensitivity to standing in crush conditions than males. This greater sensitivity to crowding amongst females and the over sampling of females compared to CityRail profile data recommended the weighting of response by gender. Gender factoring was therefore applied in the model presented Table 1.

Table 3 presents the effect of onboard crowding on the value of onboard travel time.

The values are expressed in terms of uncrowded seating (or the timetabled onboard train time).

For crowded seating, the relative value is the ratio of the estimated

Table 3: Relative Valuations

Level of Crowding	Relative to Uncrowded Seating	
	Additional Cost/min	Generalised Total Time/min
Crowded Seat	0.17	1.17
Stand up to and including 10 mins	0.34	1.34
Stand - 15 minutes	0.57	1.57
Stand - 20 minutes or longer	0.81	1.81
Crush Stand v Uncrushed Stand	0.71	na
Crush Stand up to 10 mins	1.04	2.04
Crush Stand - 15 minutes	1.28	2.28
Crush Stand - 20 minutes or longer	1.52	2.52

Notes: Additional time to ontrain 'uncrowded sitting' minutes
Total time in equivalent ontrain 'uncrowded sitting' minutes

Source: RailCorp Surveys, Douglas Economics Analysis SydCrowdRes06_2.xls!RelVal parameter for crowded seating (βcseat) to onboard train time (βv), equation 4:

Value of Crowding per minute = $\frac{\beta cseat}{\beta v} = \frac{-0.028}{-0.161} = 0.17$ …..(4)

One minute of crowded seating therefore adds 0.17 minutes to the perceived on-train travel time compared to uncrowded seating. The 'generalised total time' is therefore 1.17 minutes (1 minute of timetable time + 0.17 minutes of crowded seating time).

The cost of standing up to ten minutes is similarly determined by the ratio of the standing to onboard train time parameters. With the parameters in Table 5.1, the value of one minute of standing is equal to 0.34 minutes of uncrowded seating time. Standing for 10 minutes therefore adds 3.4 minutes to the on-train time to give a generalised total time of 13.4 minutes when expressed in equivalent uncrowded time minutes equation 5.

Value of Standing up to 10 minutes per minute = $\frac{\beta std}{\beta v} = \frac{-0.054}{-0.161} = 0.34$ …..(5)

Standing for over ten minutes adds to the cost of standing. The 20 minute stand was treated incrementally to the 10 minute stand thus the 10 and 20 minute parameter estimates needed to be added to obtain the cost of a twenty minute stand, equation 6.

Value of Standing for 20 minutes per minute = $\frac{\beta std + \beta std20}{\beta v} = \frac{-0.054 - 0.077}{-0.161} = 0.81$ …..(6)

The cost per minute of a 20 minute stand equal to 0.81 minutes of uncrowded seating time. To get the generalised total time in equivalent uncrowded minutes, the timetable time would be multiplied by 1.81 (i.e. 36.2 minutes). Standing for 10 to 20 minutes (e.g. 15 minutes) can be determined by adding the proportion of the 20 minute stand parameter to the 10 minute stand parameter. So for a 15 minute stand, the cost of standing per minute would be 0.57 minutes of uncrowded seating which would add 8.55 minutes to the timetabled time and increase the generalised time to 23.55 minutes (8.55 + 15).

Value of Standing for 15 minutes/min= $\frac{\beta std + \left[\frac{20-15}{20-10}\right].\beta std20}{\beta v} = \frac{-0.054 + \left[\frac{1}{2}\right] - 0.077}{-0.161} = 0.57$ …..(7)

It is recommended that the minute value of standing for over 20 minutes is held constant at 0.81. Thus, a 30 minute stand would add 38.7 minutes to the timetable time (1.29 x 30) to give a total generalised time of 68.7 minutes in equivalent uncrowded seating or timetable minutes.

Crush conditions add 1.17 minutes to each minute of standing, equation 8. Crush conditions are considered to be trains where passenger loads (passengers/seats) exceed 160%..

Value of 1 minute of crush standing uncrushed standing time (≤10mins) = $\frac{\beta crush}{\beta v} = \frac{-0.114}{-0.161} = 0.71$ .....(8)

Thus for a ten minute crush stand, the standing cost per minute would be 1.04 mins in equivalent uncrowded sitting time, equation 8 so the the total generalised time would be 2.04 minutes.

Value of 1 minute of crush standing on uncrushed standing time (≤10mins) = $\frac{\beta std}{\beta v} + \frac{\beta crush}{\beta v} = \frac{\beta std + \beta crush}{\beta v} \frac{-0.054 - 0.114}{-0.161} = 1.04$ ...(9)

Likewise a 15 minute crush stand, would raise the cost to 1.28 per minute and a 20 minute stand (or longer) would raise the cost to 1.52 per minute.

The application of the crush loading factor requires knowledge of the passenger load factor (passengers / seats). Equation 10 shows the calculation of the load factor for a train of 980 seats and 1,200 passengers.

$$AVL = \frac{Passengers}{Seats}\% = \frac{1{,}200}{980}\% = 122.4\% \qquad \text{.....(10)}$$

where:
AVL = Average train load expressed as a percentage
$Passengers$ = number of passengers on the train at measurement point
$Seats$ = number of seats on train

RailCorp loading surveys suggest a maximum passenger load of 200% i.e. the maximum number of passengers that can be carried per train is twice the number of seats.

Some seat crowding is assumed to occur at average passenger loads of 80%. Above 80%, the crowded seat factor is assumed to increase as the square of the passenger load reaching the full value of 0.3 at 120%.

AVL<80%: CSeatF = 0
120%≥AVL≥80%: CSeatF = $\delta CSeatF.[AVL - AVL_{\min c}]^2 = 1.875.[AVL - AVL_{\min c}]^2$ .....(11)
AVL>120%: CSeatF = 0.3

Where: $\delta CSeatF = \frac{0.17}{[AVL_{\max c} - AVL_{\min c}]^2} = \frac{0.17}{[1.2 - 0.8]^2} = 1.0625$ .....(12)
CSeatF = Crowded seat factor is the generalised time factor per minute
$AVL_{\min c}$ = average passenger load at which crowded seating occurs
$AVL_{\max c}$ = average passenger load at which maximum crowded seating cost occurs

The cost of standing is assumed to increase as the square of the passenger load above 80% reaching the full crush standing cost at a passenger load of 160%. It should be noted that the stand factor (StdF) will vary according to the length of stand.

AVL<80%: CStdF = StdF
120%≥AVL≥80%:CStdF= $StdF + \delta CStdF.[AVL - AVL_{\min std}]^2 = StdF + 1.109.[AVL - AVL_{\min std}]^2$ ...(13)
AVL>120%: CStdF = StdF + CrushStdF

Where: $\delta CStdF = \frac{[CrushStdF - StdF]}{[AVL_{crush} - AVL_{\min stdc}]^2} = \frac{[0.71]}{[1.6 - 0.8]^2} = 1.109$ .....(14)
CStdF = standing crowding factor per minute
CrushStdF = crush standing crowding factor per minute
$AVL_{\min stdc}$ = average passenger load when the cost standing increases due to crowding
AVL_{crush} = average passenger load at which the crush standing crowding factor applies

Table 4 sets out the crowding cost factor for train loads varying from empty to twice seat capacity. Although a standing cost is included for all loads, involuntary standing is unlikely to occur before the average train load reaches 75% (allows for some cars to carry more passengers than other cars).

In order to derive the total generalised travel time (expressed in uncrowded seat minutes) the onboard train time (timetable time) should be added to the additional crowding cost.

The crowded seating factor does not vary with trip length, being constant at 0.17 per minute. The stand crowding factor increases from 0.34 to 0.81 per minute as stand time increases from ten to twenty minutes (from which it remains constant). Crush conditions add 0.71 minutes to each minute of standing. Thus for a ten minute stand in crushed conditions, the additional crowding factor is 1.04.

Table 4 presents the weighted crowding cost factor for crowded seating and standing which apply to <u>all</u> passengers onboard the train.

The weights relate to the length of stand which were assumed to be 30% of passengers standing for 10 minutes, 30% for 10-20 minutes (average 15 minutes) and 40% for 20 minutes or longer.

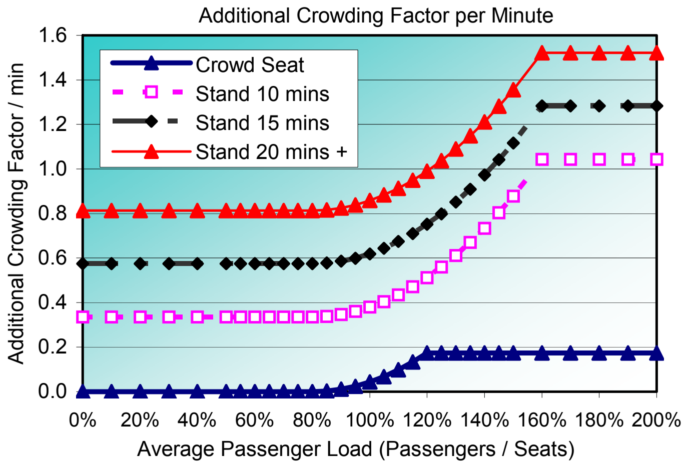
These percentages (weights) can be varied to reflect the length of stand for a particular service.

The calculation of the weighted stand factor is shown in In equation 15 below.

These percentages (weights) could be varied to derive appropriate additional crowding factors.

Table 4: Relative Valuations with Train Load

Train Load Passengers / Seats	Crowding Factor per minute Crowd Seat	Stand 10 mins	Stand 15 mins	Stand ≥20 mins
0%	0.00	0.34	0.57	0.81
10.0%	0.00	0.34	0.57	0.81
20.0%	0.00	0.34	0.57	0.81
30.0%	0.00	0.34	0.57	0.81
40.0%	0.00	0.34	0.57	0.81
50.0%	0.00	0.34	0.57	0.81
55.0%	0.00	0.34	0.57	0.81
60.0%	0.00	0.34	0.57	0.81
65.0%	0.00	0.34	0.57	0.81
70.0%	0.00	0.34	0.57	0.81
75.0%	0.00	0.34	0.57	0.81
80.0%	0.00	0.34	0.57	0.81
85.0%	0.00	0.34	0.58	0.82
90.0%	0.01	0.35	0.59	0.82
95.0%	0.02	0.36	0.60	0.84
100.0%	0.04	0.38	0.62	0.86
105.0%	0.07	0.40	0.64	0.88
110.0%	0.10	0.43	0.67	0.91
115.0%	0.13	0.47	0.71	0.95
120.0%	0.17	0.51	0.75	0.99
125.0%	0.17	0.56	0.80	1.04
130.0%	0.17	0.61	0.85	1.09
135.0%	0.17	0.67	0.91	1.15
140.0%	0.17	0.73	0.97	1.21
145.0%	0.17	0.80	1.04	1.28
150.0%	0.17	0.88	1.12	1.36
160.0%	0.17	1.04	1.28	1.52
170.0%	0.17	1.04	1.28	1.52
180.0%	0.17	1.04	1.28	1.52
190.0%	0.17	1.04	1.28	1.52
200.0%	0.17	1.04	1.28	1.52



Source:RailCorp Surveys, Douglas Economics Analysis SydCrowdRes06_2.xls!RelVal

$$WStdF = \Pr(Std_{\leq 10\min}).CStdF_{\leq 10\min} + \Pr\left(STD_{10-20\min}\right).CStdF_{15\min} + \Pr\left(STD_{\geq 20\min}\right).CStdF_{\geq 20\min} \quad .....(15)$$

$$Eg: WstdF = 0.3.CStdF_{\leq 10\min} + 0.3.CStdF_{15\min} + 0.4.CSTdF_{\geq \min}$$

where:

$WStdF$ = weighted additional crowded standing factor

$CStdF_t$ = additional crowding standing factor for standing for t minutes

$\Pr(Std_t)$ =proportion of standing passengers standing for t minutes

The weighted standing cost is then added to the crowded seating cost to derive the additional crowding cost per passenger minute:

$ACF = WStdF + CSeatF$ .....(16)

where

ACF = Additional crowding factor taking into account standing and crowded seating

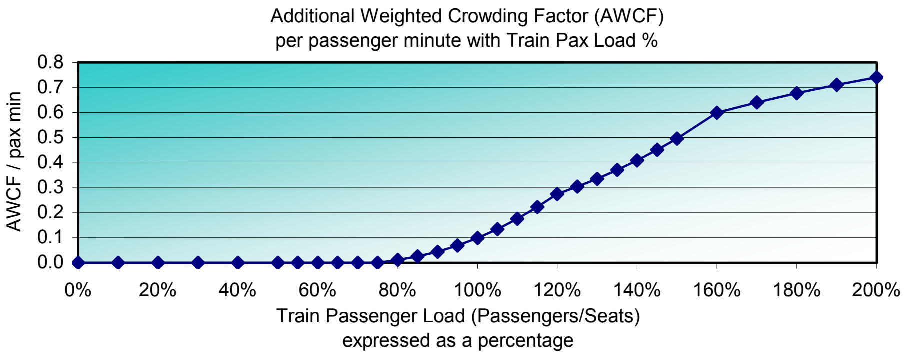
$CSeatF$ = crowded seating factor

The generalised time crowding factor (GTCF) is one plus the additional crowding factor.

$GTCF = 1 + ACF$ .....(17)

Table 5: Average Passenger Crowding Factors for Individual Train Loads

Train Load Passengers / Seats	Percent Sit	Percent Stand	Additional Crowding Factor / pax min: Seat Crowd	Stand 10 mins	Stand 15 mins	Stand 20 mins	Crowding Factor / pax min: Additional AWCF	Generalised GWCF
0%	100%	0%	0.00	0.00	0.00	0.00	0.00	1.00
10%	100%	0%	0.00	0.00	0.00	0.00	0.00	1.00
20%	100%	0%	0.00	0.00	0.00	0.00	0.00	1.00
30%	100%	0%	0.00	0.00	0.00	0.00	0.00	1.00
40%	100%	0%	0.00	0.00	0.00	0.00	0.00	1.00
50%	100%	0%	0.00	0.00	0.00	0.00	0.00	1.00
55%	100%	0%	0.00	0.00	0.00	0.00	0.00	1.00
60%	100%	0%	0.00	0.00	0.00	0.00	0.00	1.00
65%	100%	0%	0.00	0.00	0.00	0.00	0.00	1.00
70%	100%	0%	0.00	0.00	0.00	0.00	0.00	1.00
75%	100%	0%	0.00	0.00	0.00	0.00	0.00	1.00
80%	98%	2%	0.00	0.01	0.01	0.02	0.01	1.01
85%	96%	4%	0.00	0.01	0.02	0.03	0.02	1.02
90%	94%	6%	0.01	0.02	0.03	0.05	0.04	1.04
95%	93%	7%	0.02	0.03	0.04	0.06	0.07	1.07
100%	91%	9%	0.04	0.04	0.06	0.08	0.10	1.10
105%	89%	11%	0.06	0.04	0.07	0.10	0.13	1.13
110%	87%	13%	0.09	0.06	0.09	0.12	0.18	1.18
115%	85%	15%	0.11	0.07	0.11	0.14	0.22	1.22
120%	83%	17%	0.14	0.09	0.13	0.17	0.27	1.27
125%	80%	20%	0.14	0.11	0.16	0.21	0.30	1.30
130%	77%	23%	0.13	0.14	0.20	0.25	0.34	1.34
135%	74%	26%	0.13	0.17	0.24	0.30	0.37	1.37
140%	71%	29%	0.12	0.21	0.28	0.35	0.41	1.41
145%	69%	31%	0.12	0.25	0.32	0.40	0.45	1.45
150%	67%	33%	0.12	0.29	0.37	0.45	0.50	1.50
160%	63%	38%	0.11	0.39	0.48	0.57	0.60	1.60
170%	59%	41%	0.10	0.43	0.53	0.63	0.64	1.64
180%	56%	44%	0.10	0.46	0.57	0.68	0.68	1.68
190%	53%	47%	0.09	0.49	0.61	0.72	0.71	1.71
200%	50%	50%	0.09	0.52	0.64	0.76	0.74	1.74



Notes: 30% standing passengers stand for 10 mins; 30% 10-20 minutes (av = 15) and 40% ≥20 minutes
Assumes zero standing at a load of ≤ 80%, standing % increases linearly to 17% of passengers at 20%
then increases at {(Av Load -1)/Av Load } > 120% to reach maximum of 50% at 200% Average Load
Source:RailCorp Surveys, Douglas Economics Analysis SydCrowdRes06_2.xls!RelVal

The questionnaire also assessed passengers' attitudes and exposure to crowding, Douglas Economics (2006). In terms of the exposure to crowding passengers were asked "of the last ten times you have made this trip around this time, how many were in uncrowded seating; crowded seating; standing and crush standing (respondents were shown example photographs as used in the Stated Preference questions). 29% of AM and PM peak trips were made in uncrowded conditions, 43% in crowded seat conditions, 17% in standing conditions and 11% in crush standing conditions.

The exposure to crowding was applied to the relative crowding valuations to derive an average additional crowding factor of 0.53 for the peak and an average generalised total time factor of 1.53. Equation 18 shows the calculation:

$$\bar{CF} = \sum_c ACF_c . CEW_c \quad ...(18)$$

where:

$\bar{CF}$ = Average additional crowding factor for the peak
ACF_c = Additional crowding factor for crowding level c
CEW_c = Percentage of peak trips exposed to crowding level c

The value of onboard train time for peak travel was estimated at \$9.46 per hour by Stated Preference market research undertaken by Douglas Economics in 2004.[3] The value of \$9.46 per hour is argued to incorporate an average level of crowding.

The crowding factor of 0.12 (Table 7.3) was used to separate out the crowded and uncrowded components of the value of on-train time.

VoT (uncrowded) = $$\frac{V\bar{o}T}{1+\bar{CF}} = \frac{\$9.46/hr}{1+0.12} = \$8.45/hr \quad .....(19)$$

VoT (additional crowding) = $$V\bar{O}T - VOT(uncrowded) = \$9.46/hr - \$8.45hr = \$1.01/hr \quad .....(20)$$

The uncrowded component was estimated at \$8.45/hr. Crowding was estimated to add \$1.01 per hour. Table 7 sets out the value of on-train travel time under different levels of crowding. Crowded seating adds \$2.33 per hour to the uncrowded value of \$8.45/hr raising the generalised cost to \$9.92/hr. Standing adds 4.7 cents per minute for stands of up to 10 minutes i.e. 47 cents in total for a 10 minute stand. Crush standing adds 10 cents per minute compared to uncrushed standing.

Table 7: Money Value of Crowded Seating & Standing

Level of Crowding	Relative to Uncrowded Seating: Additional Cost		Generalised Cost	
	Cents/min	Dollars/Hour	Cents/min	Cost $/hr
Uncrowded Seating	14.1	8.45	14.1	8.45
Crowded Seat	2.4	1.47	16.5	9.92
Stand up to and including 10 mins	4.7	2.83	18.8	11.28
Stand - 15 minutes	8.1	4.85	22.2	13.30
Stand - 20 minutes or longer	11.5	6.88	25.5	15.33
Crush Stand v Uncrushed Stand	10.0	5.98	24.1	14.43
Crowding Factor	1.7	1.01	15.8	9.46

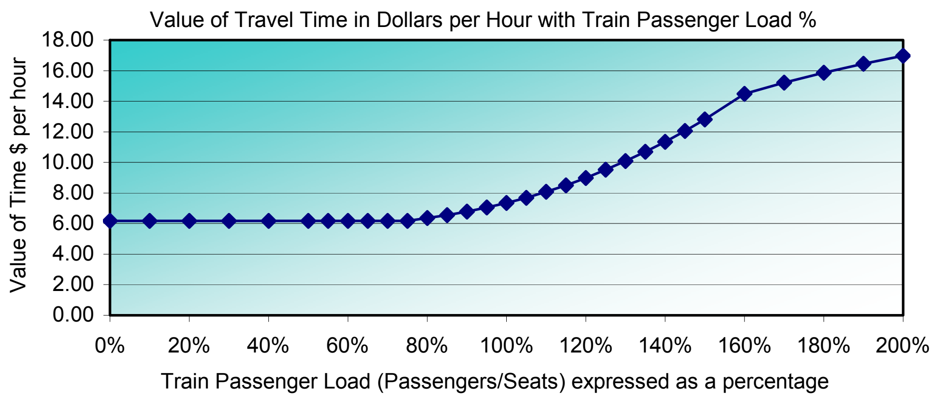
Note: Values include GST
Source: RailCorp Surveys, Douglas Economics Analysis
SydCrowdRes06_2.xls!RelVal

[3] "Value of Rail Travel Time" for RailCorp Train Service Rail Development, by Douglas Economics, May 2004.

Table 8 presents the cost of on-train time with different crowding levels for an individual train and shows the value of time to increase from $8.45 per hour to $8.84 at 100% loading and reach $12.05 per hour at 200% train loads.

Table 8: Value of Travel Time with Train Loading

Train Load Passengers / Seats	Percent Sit	Percent Stand	Additional Crowd Cost Cents/pax min: Seat Crowd	Stand 10 mins	Stand 15 mins	Stand 20 mins	Additional Crowding Cost Cents/pax min	Generalised Cost: Cents / pax min	Dollars / hour
0%	100%	0%	0.0	0.0	0.0	0.0	0.0	10.3	6.18
10.0%	100%	0%	0.0	0.0	0.0	0.0	0.0	10.3	6.18
20.0%	100%	0%	0.0	0.0	0.0	0.0	0.0	10.3	6.18
30.0%	100%	0%	0.0	0.0	0.0	0.0	0.0	10.3	6.18
40.0%	100%	0%	0.0	0.0	0.0	0.0	0.0	10.3	6.18
50.0%	100%	0%	0.0	0.0	0.0	0.0	0.0	10.3	6.18
55.0%	100%	0%	0.0	0.0	0.0	0.0	0.0	10.3	6.18
60.0%	100%	0%	0.0	0.0	0.0	0.0	0.0	10.3	6.18
65.0%	100%	0%	0.0	0.0	0.0	0.0	0.0	10.3	6.18
70.0%	100%	0%	0.0	0.0	0.0	0.0	0.0	10.3	6.18
75.0%	100%	0%	0.0	0.0	0.0	0.0	0.0	10.3	6.18
80.0%	98%	2%	0.0	0.1	0.3	0.5	0.3	10.6	6.36
85.0%	96%	4%	0.0	0.2	0.5	1.0	0.6	10.9	6.56
90.0%	94%	6%	0.1	0.3	0.8	1.5	1.0	11.3	6.79
95.0%	93%	7%	0.2	0.4	1.1	2.0	1.4	11.7	7.05
100.0%	91%	9%	0.3	0.5	1.4	2.6	1.9	12.2	7.35
105.0%	89%	11%	0.5	0.6	1.8	3.2	2.5	12.8	7.69
110.0%	87%	13%	0.7	0.8	2.2	3.9	3.1	13.4	8.07
115.0%	85%	15%	0.9	1.0	2.6	4.6	3.9	14.2	8.50
120.0%	83%	17%	1.2	1.2	3.1	5.4	4.7	15.0	8.98
125.0%	80%	20%	1.1	1.6	4.0	6.8	5.6	15.9	9.52
130.0%	77%	23%	1.1	2.0	4.9	8.3	6.5	16.8	10.09
135.0%	74%	26%	1.1	2.5	5.9	9.9	7.5	17.8	10.69
140.0%	71%	29%	1.0	3.0	7.0	11.5	8.6	18.9	11.35
145.0%	69%	31%	1.0	3.6	8.1	13.2	9.8	20.1	12.05
150.0%	67%	33%	0.9	4.2	9.3	15.1	11.0	21.3	12.81
160.0%	63%	38%	0.9	5.7	12.0	19.1	13.8	24.1	14.49
170.0%	59%	41%	0.8	6.2	13.2	21.0	15.1	25.4	15.22
180.0%	56%	44%	0.8	6.7	14.2	22.7	16.1	26.4	15.87
190.0%	53%	47%	0.7	7.2	15.1	24.2	17.1	27.4	16.45
200.0%	50%	50%	0.7	7.6	16.0	25.5	18.0	28.3	16.97



Notes: 30% standing passengers stand for 10 mins; 30% 10-20 minutes (av = 15) and 40% ≥20 minutes
Assumes zero standing at a load of ≤ 80%, standing % increases linearly to 17% of passengers at 20%
then increases at {(Av Load -1)/Av Load } > 120% to reach maximum of 50% at 200% Average Load
Source:RailCorp Surveys, Douglas Economics Analysis SydCrowdRes06_1.xls!RelVal

It should be noted that Table 8 refers to an individual train. Time period assessment would need to take of the variability in individual train loads within the peak period. Douglas Economics (2006) uses train loading data to develop a time period model which gives higher crowding costs at lower loadings (reflecting variability between trains) but nearly identical costs at high passenger loads.

5. Review of Crowding Values

The crowding costs were lower than the previous 1995 survey of Sydney rail passengers. The 2005 additional crowded seating factor of 0.17 was one quarter the 1995 factor of 0.6. The 2005 crowding factors which ranged from 0.54 for short uncrushed stands to 2.46 per minute for 20 minute stands compared with the 1995 factor of 1.4. Thus the 2005 standing factors straddled the 1995 factor.

The estimated crowding factors were also compared against UK rail and LUL values. Based on a review of studies, the UK Passenger Demand Forecasting Council, PDFC (2002) developed a set of crowding factors.[4] The recommended values for commuting to work trips are presented in Table 10 alongside the Sydney values. At the maximum passenger load of 160% tabulated by the UK PDFC, the UK rail crowded seating value of 0.4 (for a passenger load of 160%) is double the Sydney value of 0.17. However at loadings of 120-140% the values are similar. At 140% for example, the UK PDFC recommends values of 0.14 for Outer London and 0.26 for Non London flows which compares with 0.17 for Sydney.

Table 10: Comparison of UK & Sydney Crowding Costs

Load Factor	Crowded Seating			Standing			Sydney Values	
	Inner London	Outer London	Non London	Inner London	Outer London	Non London	Seating	Standing
50%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
60%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
70%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
80%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
90%	0.00	0.02	0.04	0.00	0.00	0.00	0.00	0.00
100%	0.06	0.05	0.09	1.13	1.13	0.71	0.02	0.62
110%	0.11	0.07	0.13	1.18	1.18	0.77	0.07	0.67
120%	0.17	0.09	0.18	1.23	1.23	0.82	0.13	0.73
130%	0.23	0.12	0.22	1.27	1.27	0.88	0.17	0.82
140%	0.28	0.14	0.26	1.32	1.32	0.93	0.17	0.93
150%	0.34	na	na	1.37	1.37	0.99	0.17	1.07
160%	0.40	na	na	1.42	1.42	1.04	0.17	1.14

Crowding factors based on pence/mile crowding costs. Figures converted
to equivalent onboard time by assuming a 25 mile trip and an onboard value of
(uncrowded) time of 10.6 mile for London and 9.1p/mile for Non London
Sydney standing values provided for >=5% of passengers standing
Source: UK Passenger Demand Forecasting Handbook Table B5.1
SydCrowdRes06_2.xls!UK Values

The UK PDFC standing factors for Non London flows are similar to the Sydney values. For a 100% load, the UK PDFC recommends a factor of 0.71 per minute for Non London flows which compares with a standing factor for Sydney of 0.62 (adopting the stand length distribution footnoted in Table 6.4). Compared to Inner and Outer London flows however, the standing factor for Sydney is only around one half the size (0.62 versus 1.13).

At the maximum UK tabulated loadings of 160%, the UK PDFC factors increase to 1.42 for Inner and Outer London and 1.04 for non London. These factors compare with a crowding

[4] The original values were presented in pence per minute rather than equivalent onboard travel time. Table 10 has converted the values into uncrowded onboard rail time by referencing average onboard travel time values. It should be noted that the UK factors do not vary with the length of stand.

factor of 1.14 for Sydney. The Sydney value therefore falls between the Non London and London values.

In 1988, London Underground undertook an observation study of passenger behaviour at stations where the there was a choice of catching an uncrowded train starting from the observation station or catching a generally crowded train that had started from a previous station (e.g. Severn Sisters), LUL (1988).

LUL by noting the proportion of passengers who waited for an empty train they were able to deduce the trade-off of crowding against waiting time. The study estimated an additional crowding factor of 0.4 when only a few people were standing up to a crowding factor of 1.7 times in crush-load conditions. At half crush-load conditions, an additional crowding factor of 1 was calculated.

The LUL factors are broadly similar to the Sydney values. The LUL uncrushed standing factor of 0.4 compares with the Sydney factors of 0.34 for a ten minute uncrushed stand and 0.81 for a 20 minute uncrushed stand. For crush conditions, the LUL additional crowding factor of 1.7 is higher than the Sydney values of 1.01 for a ten minute crush stand and 1.52 for a twenty minute crush stand.

6. Worked Example

Consider a proposal to run an additional service to reduce passenger crowding on a peak train service. Table 11 provides the passenger and capacity data.

Table 11: Service Details & Passenger Loads

Base Case with 920 Seats

1	2	3	4	5	6	7	8	9	10	11
								Estimated		
	Arrival	Station -		Passenger		Seat	Load	Percent	Percent	Number
Stop	Time mins	Station mins	Ons	Offs	Onboard	Capacity	Factor	Sit	Stand	Standing
A	0	15	300	0	300	920	33%	100%	0%	0
B	15	15	500	100	700	920	76%	100%	0%	0
C	30	10	600	50	1,250	920	136%	74%	26%	324
D	40	10	300	50	1,500	920	163%	61%	39%	590
E	50	10	300	50	1,750	920	190%	53%	47%	829
F	60		0	1,750	0	920	na	na	na	na
	Total		2,000	2,000						

Forecast Option with 1840 Seats

1	2	3	4	5	6	7	8	9	10	11
								Estimated		
	Arrival	Station -		Passenger		Seat	Load	Percent	Percent	Number
Stop	Time mins	Station mins	Ons	Offs	Onboard	Capacity	Factor	Sit	Stand	Standing
A	0	15	300	0	300	1840	16%	100%	0%	0
B	15	15	500	100	700	1840	38%	100%	0%	0
C	30	10	600	50	1,250	1840	68%	100%	0%	0
D	40	10	300	50	1,500	1840	82%	98%	2%	28
E	50	10	300	50	1,750	1840	95%	93%	7%	130
F	60		0	1,750	0	1840	na	na	na	na
	Total		2,000	2,000						

Numbers may not sum due to rounding

Source; Douglas Economics SydCrowdRes06_1.xls!worked example

The top half presents the base case (1 train of 920 seats) and the bottom half the option situation (2 trains totalling 1,840 seats). The service stops at six stations (A, B....F) with station – station times shown in column 3. Passenger surveys establish the station ons and offs in column 4-6 from which onboard totals are calculated in column 6.

The base case service is provided by an eight car train with a seating capacity of 920 (col 7). The passenger load factor (col 8) is calculated by dividing the onboard passenger total (col 6) by the train capacity (col 7) for each station-station section. On departing station E for example, the load factor is 190% in the base case and 95% in the option case.

The estimated percentage of passengers standing is determined by referencing the load factor (col 8) in Table 5. For the load factor of 136% between stations C&D, the predicted percent of passengers standing is 26% (a load factor of 135% was the 'look up' percentage in Table 5). The number standing (col 11) between each station was the number onboard (col 6) times the percentage standing (col 10) which was 324 between stations C and D. The percentage of passengers (col 9) seated was 74% (100%-26%). By comparison, the doubling of capacity for the forecast option reduces standing to 7% between stations E&F.

The additional perceived time due crowded seating (col 13) and standing (cols 14-16) is referenced from Table 5. Thus for the base case service departing station E, with 190% passenger loading, the seat crowding factor from Table 5 is 0.09 per minute with additional standing factors of 0.49, 0.61 and 0.72 minutes per minute of travel time for passengers standing for up to 10 minutes, 10-20 minutes and greater than 20 minutes respectively.

Table 12: Estimated Crowding Time

Base Case with 920 Seats

1	8	12	13	14	15	16	17	18
		Additional Crowding Time Factor per min				Additional	Generalised	Total
Stop	Load Factor	Seat Crowd	Stand ≤10 mins	Stand 15 mins	Stand ≥20 mins	Crwd Factor / pax min	Crwd Factor / pax min	Generalised Time mins
A	33%	0.00	0.00	0.00	0.00	0.00	1.00	4,500
B	76%	0.00	0.00	0.00	0.00	0.00	1.00	10,500
C	136%	0.13	0.17	0.24	0.30	0.38	1.38	17,198
D	163%	0.11	0.41	0.50	0.60	0.63	1.63	24,408
E	190%	0.09	0.49	0.61	0.72	0.72	1.72	30,096
F	na	na	na	na	na	na	na	na
		Weight	40.9%	0.0%	59.1%		Total	86,702
							Average	43.4

Forecast Option with 1840 Seats

1	8	12	13	14	15	16	17	18
		Additional Crowding Time Factor per min				Additional	Generalised	Total
Stop	Load Factor	Seat Crowd	Stand ≤10 mins	Stand 15 mins	Stand ≥20 mins	Crwd Factor / pax min	Crwd Factor / pax min	Generalised Time mins
A	16%	0.00	0.00	0.00	0.00	0.00	1.00	4,500
B	38%	0.00	0.00	0.00	0.00	0.00	1.00	10,500
C	68%	0.00	0.00	0.00	0.00	0.00	1.00	12,500
D	82%	0.00	0.01	0.01	0.02	0.01	1.01	15,093
E	95%	0.02	0.03	0.04	0.06	0.05	1.05	18,363
F	na	na	na	na	na	na	na	na
		Weight	100.0%	0.0%	0.0%		Total	60,957
							Average	30.5

Numbers may not sum due to rounding

Source; Douglas Economics SydCrowdRes06_2.xls!worked example

The additional cost per passenger minute (col 16) is calculated by weighting the additional standing cost per minute for ≤10 minutes, 15 minutes (i.e. 10-20 minutes) and ≥20 minutes by the percentage of standing passengers standing for that length of time and adding the weighted total to the crowded seating cost. The adopted weights (40.9% up to 10 mins and 59.1% ≥20 minutes) were determined on a probabilistic basis given the section lengths, onboard totals and train off estimates. The generalised crowding factor (col 17) was equal to 1 + Additional Crowding Factor (col 16).

The total generalised onboard time including crowding is the product of the generalised crowding factor (col 17), the onboard passenger number (col 6) and the section – section time (col 3). Summing over the station – station sections gives a total of travel time including crowding of 86,702 minutes with an average generalised time of 43.4 minutes per passenger. With the additional capacity, the total generalised onboard time including crowding reduces to 60,957 minutes with an average generalised time per passenger of 30.5 minutes.

Table 13 calculates the dollar cost of crowding. The additional cost due to crowded seating (col 19) and standing (cols 20-22) is referenced from Table 9.

Table 13: Estimated Crowding Cost in Dollars

Base Case with 920 Seats

1	8	19	20	21	22	23	24
		Additional Crowd Cost Cents/pax min				Additional	
	Load	Seat	Stand	Stand	Stand	Crowding Cost	Crowding
Stop	Factor	Crowd	≤10 mins	15 mins	≥20 mins	Cents/pax min	Cost $
A	33%	0.00	0.00	0.00	0.00	0.00	0
B	76%	0.00	0.00	0.00	0.00	0.00	0
C	136%	0.22	0.50	1.07	1.85	1.52	190
D	163%	0.18	1.14	2.21	3.58	2.77	415
E	190%	0.16	1.41	2.76	4.49	3.39	593
F	na	na	na	na	na	na	na
		Weight	40.9%	0.0%	59.1%	Total	1,199
						Average	0.60

Forecast Option with 1840 Seats

1	8	19	20	21	22	23	24
		Additional Crowd Cost Cents/pax min				Additional	
	Load	Seat	Stand	Stand	Stand	Crowding Cost	Crowding
Stop	Factor	Crowd	≤10 mins	15 mins	≥20 mins	Cents/pax min	Cost $
A	16%	0.00	0.00	0.00	0.00	0.00	0
B	38%	0.00	0.00	0.00	0.00	0.00	0
C	68%	0.00	0.00	0.00	0.00	0.00	0
D	82%	0.00	0.02	0.05	0.09	0.02	3
E	95%	0.04	0.08	0.20	0.39	0.12	20
F	na	na	na	na	na	na	na
		Weight	100.0%	0.0%	0.0%	Total	23
						Average	0.01

Numbers may not sum due to rounding

Source; Douglas Economics SydCrowdRes06_2.xls!worked example

Thus for the base case service departing station E, with a 190% passenger loading, the additional cost from crowded seating was 0.16 per minute with additional standing factors of 1.41, 2.76 and 4.49 cents per minute for passengers standing for up to 10 minutes, 10-20 minutes and greater than 20 minutes respectively.

The additional cost per passenger minute (col 23) was calculated by weighting the additional standing cost per minute in the same way as the additional crowding time.

The total crowding cost (col 24) for each station to station section was determined by multiplying the additional crowding cost (col 23) by the onboard passenger number (col 6) by the section time (col 3). The total crowding cost for all passengers on the train in the base case was $1,199 with an average cost per passenger of $0.60.With capacity doubled, total crowding reduces to $23 with an average cost of just 1 cent per passenger. Therefore in net terms, doubling capacity reduced the total cost of crowding by $1,176 and by 59 cents per passenger.

It should be noted that the calculation of benefit did not include any reduction in waiting time from the extra train or any reduction in station dwell times due to faster boarding and alighting (from the doubling of the train carriage doors, aisle and vestibule capacity) or allow for any peak spreading.

7. Concluding Remarks

Passenger response to the market research survey found standing and crowded seating to increase the cost of rail travel as perceived by passengers. Standing for over 10 minutes and standing in crush conditions are particularly costly. Gender was found to influence the cost of crowding with females having a higher cost associated with standing in crushed conditions than males.

The estimated crowding valuations were converted into a continuous measure by reference to a crowding density function. The resultant crowding function can be used in travel demand models or in assessments of different rolling stock options or rail capacity upgrades.

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