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Forecasting Walk Diversion to Light Rail

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Abstract

The Public Transport Project Model (PTPM) developed by TfNSW forecasts the demand for mechanized modes i.e. rail, bus, ferry, car and taxi. Active transport (walking and cycling) has not been modelled. For rail projects outside the CBD, such as the North West Rail Link (NWRL), the omission of walk/cycle has not been significant because of the long travel distances. However for Light Rail, where stops can be close together along corridors with high pedestrian counts, the omission of walk could underestimate patronage. Thus for Sydney CBD-SE LRT, walk trips were forecast using a spreadsheet model describing detailed zones.

This paper looks at three different ways of forecasting walk diversion in PTPM. A pragmatic, simplistic approach is to apply a walk diversion factor expressed relative to 'mechanized mode' diversion. A review of market research studies produced a factor of 1.124.

TfNSW also has a Strategic Travel Model (STM) that includes walk as a travel mode so it was a natural candidate to provide a forecast of walk diversion. However, as with most Four Stage Models, STM is not sufficiently accurate at the corridor level to produce reliable forecasts.

A third approach is to model walk diversion within PTPM.

1 Introduction

The Transport Performance and Analytics (TPA) business unit within Transport for NSW (TfNSW) has developed a Public Transport Project Model (PTPM) to forecast patronage and user benefit, see Douglas and Jones (2016).

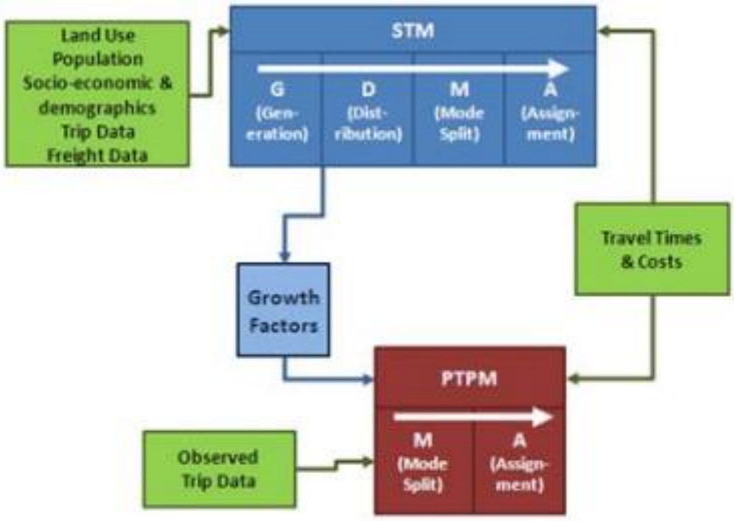
PTPM was first used to forecast patronage for the North West Rail Link in 2011. Its second application was the CBD and South East Light Rail. Other projects include the Northern Beaches Bus Rapid Transit, Parramatta Light Rail and Sydney Metro West.

Figure 1 shows the structure of PTPM. It is a multi-modal model that forecasts incrementally by pivoting off observed matrices thereby avoids the errors in predicting base demand. It is this feature that distinguishes it from STM which is a conventional 4 Stage Transport Demand Model and which forecasts absolutely.

STM which is a 24 hours tour-based model forecasts of exogenous (population/land use) growth are inputs into PTPM which is a trip based model that forecasts for the weekday AM peak. Travel times and costs are 'inputs' into both models. PTPM forecasts mode choice, station and service 'assignment' largely according to a measure of generalised travel time.

PTPM forecasts the demand for mechanized modes (rail, bus, ferry and car and taxi) but does not model walking and cycling. For heavy rail projects the 'omission' is not likely to affect forecasts given long trip distances. However, for Light Rail where stops can be close together in dense urban environments e.g. George Street Sydney CBD, omitting walk will underestimate LRT patronage. Accordingly, for the Sydney CBD-SE LRT, an add-on spreadsheet model forecast walk diversion.

Figure 1: Public Transport Project Model



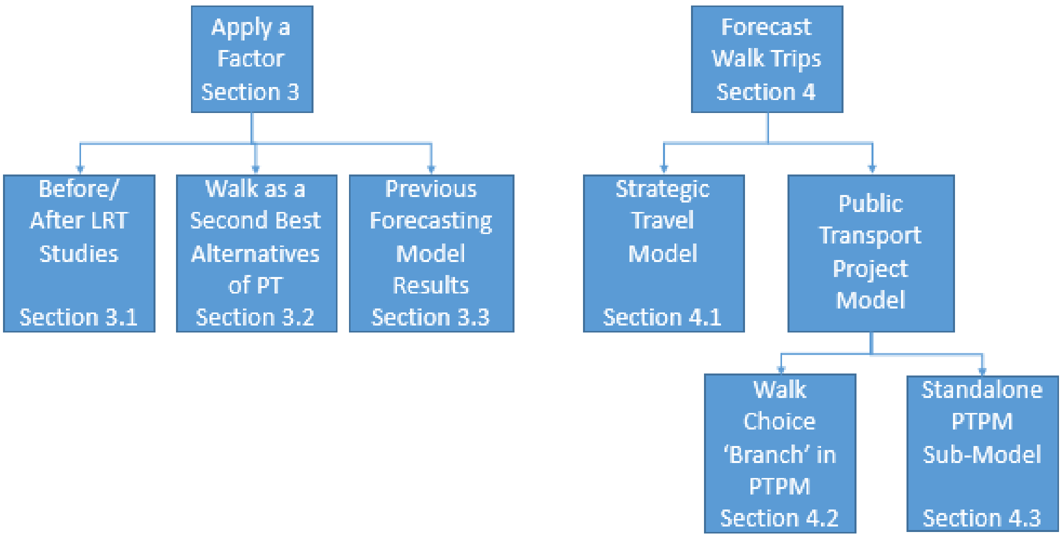
Douglas and Jones (2016)

There is a view that modelling walk is unnecessary since LRT will often replace buses. If people prefer to walk rather than catch a bus they are likely to walk rather than catch LRT. This may be correct for short walk trips (particularly for trips that start and finish close to bus or LRT stops) but if boarding and alighting is made easier by LRT or if the LRT route and stops are more 'visible', or if LRT is free then the number of walk trips diverting to LRT is likely to be significant.

There are also projects where pedestrianization accompanies LRT, such as Sydney CBD-SE LRT where George St has been pedestrianized, which could encourage 'hop on' and 'hop off' trips.

TfNSW therefore decided to look at methods to forecast walk diversion. Figure 2 shows the alternative methods.

Figure 2: Typology of Approaches to include Walk Diversion within PTPM



The rest of this paper is as follows. After assessing the size of the walk market in section 2, Section 3 looks at developing a factor for likely walk diversion that can multiply with the existing PTPM forecasting of ‘mechanised’ travel diversion. Section 4 addresses two approaches to forecast walk diversion either using STM or within PTPM. Section 5 compares and contrasts the different approaches.

2 Size of the Walk Market

In 2006, walk had a 14% share all day trips across Sydney, Newcastle and Wollongong based on TfNSW Household Travel Survey (HTS) data.[1]

Table 1: Walk Share of All Day Trips in Sydney (2006)

Mode	Commute	Business	Education	Other	Total
Car	1,158,460	779,946	363,153	3,101,969	5,403,528
Public Transport	303,428	35,948	176,897	180,412	696,685
Walk	87,272	77,267	112,586	757,967	1,035,092
Cycle	7,682	3,046	8,146	33,808	52,682
Taxi	5,172	13,890	1,444	16,293	36,799
Total	1,556,842	896,207	660,782	4,074,156	7,187,987
Mode	Commute	Business	Education	Other	Total
Car	74%	87%	55%	76%	75%
Public Transport	19%	4%	27%	4%	10%
Walk	6%	9%	17%	19%	14%
Cycle	0%	0%	1%	1%	1%
Taxi	0%	2%	0%	0%	1%
Total	100%	100%	100%	100%	100%

Source: TfNSW Household Travel Survey (2006)

Walk’s share was highest for ‘other’ trips (19%) and lowest for commuting (6%). Cycle’s share was negligible.

Overall, walk had a higher share (14%) than public transport share (10%). The share was highest for ‘other’ trips like shopping (19%) and lowest for commuting (6%). Cycling had a negligible share.

A limitation of the HTS data is that only residents and not tourists were surveyed. There is also a view that HTS does not capture ‘all’ walk trips with office to office trips and short walks (e.g. to the coffee shop) being under reported.

Walk trips were relatively short averaging 2.3kms as Table 2 shows. Commute walks tended to be longer averaging 3.1 kms whereas walk in the course of work were at around 1.9kms.

Cycle trips were three times longer than walk trips (6.6 kms versus 2.3 kms) with public transport trips considerably longer at 36kms. Thus many public transport trips are simply too long for walk to be considered.

[1] These estimates are for walking ‘all the way’ and exclude walk as access or egress to PT. The figures are for 2006 and were taken from RAND TR949 Appendix C.

Table 2: Average Trip (Half Tour) Length in kilometres Sydney Metropolitan Area 2006

	Commute	Business	Education	Other	Total
Car	28.5	26.5	12.2	12.5	17.9
Public Transport	44.1	42.8	23.6	33.0	36.0
Walk	3.1	1.9	2.5	2.2	2.3
Cycle	11.2	7.8	4.8	5.9	6.6
Taxi	10.0	12.7	14.0	11.3	11.8
Total	30.0	25.0	13.5	11.4	17.4

Source: Sydney Travel Model (2006)

3 Applying a Walk Diversion Trip Factor

The simplest way to include diversion from walk trips to LRT is to apply a factor to forecast mechanised trip diversion (DIV_{MECH}). The factor would account for the proportion of diverted walk trips ($Pr(_{WALK})$) of total diverted trips (DIV_{ALL}), Equation 1.

$$DIV_{ALL} = DIV_{MECH}\left(\frac{1}{1-\Pr(WALK)}\right) \ldots.(1)$$

Three sources of evidence were reviewed to derive a factor: (1) before and after studies; (2) passenger surveys of second best alternatives and (3) patronage forecasts of three LRT projects in Sydney CBD. Each one is reviewed in turn.

3.1 Before and After Surveys

Before and after studies are the best source of information on the size of a diversion factor. Unfortunately, only four ‘before and after’ LRT studies were found in the literature: Croydon Light Rail in London, Tenerife, Manchester and Sheffield. The literature review was unable to find a published Australian ‘Before and After’ study despite the recent renaissance of LRT in Australia, see Douglas and Cockburn (2019).

Figure 3: Croydon Tram

Tram leaving Croydon towards Wimbledon at Reeves Corner in 2009.
Photo by Peter Trimming (Wikipedia)

Croydon Light Rail (Tramlink) opened in May 2000 and has 39 stops on 28 kms of track (0.7kms/stop). The route has street track shared with other traffic; dedicated track on public roads; off-street track consisting of new rights-of-way, former railway lines and one right-of-way section where the Tramlink parallels the existing railway.

A Household Travel Survey was undertaken before and after the tram's introduction. 4% of respondents had previously made their trips by walking, Table 3. Most had diverted from bus however (69%) with 19% from car (16% drivers and 3% passengers). A further 7% were previous rail users and 1% had made the trip by 'other' means.[2]

Thus in summary, people who had previously walked contributed 4% of Tramlink patronage with the low share considered to reflect the high share of 'on-rail' rather than 'on-street' running of the tram.

Table 3: Before & After Study of Croydon Tramlink (circa 2000)

Annual Trips by Source	Trips Per year	Percent
Bus	9,316	69%
Car as Driver	2,160	16%
Car as Passenger	405	3%
Rail	945	7%
Walk	540	4%
Other	135	1%
Total	13,501	100%

Source Thomas (2002)

A 'Before and After' study was undertaken of Tenerife Light Rail by Gonzalez et al (2016).[3]

LRT operations started in June 2007 linking La Laguna with Santa Cruz via the University Hospital (12.5 kms and 21 stops). It carries around 12 million passengers a year with many being students attending the University of La Laguna (20,000 students). It is also well used by tourists.[4]

The 'Before and After' study was undertaken of students. Other users were not surveyed. After correcting for an unexpected increase in car share (rationalised as older students buying cars) walk contributed 15% of LRT demand with bus contributing 85%.

An alternative estimate was based on the mode choice of students in 2009 (after the LRT was introduced) by looking at how students travelled before the LRT was introduced.

Just over half (54%) who walked in 2007 chose LRT in 2009. 8% of car users and 62% of bus users chose LRT. Multiplying these percentages by their trip share, gave the source of LRT patronage as 15% walk, 11% car and 74% bus.

[2] A summary can be downloaded via http://www.transecongroup.org/Transport_Economist_30-2.pdf

[3] The study surveyed over 2,000 students in three waves over a period 2007 – 2009 (about 10% of the total student population). Detailed analysis was limited to 284 students who completed the 2007 and 2009 surveys and met other criteria.

[4] A second line was added in 2009 which increased the patronage to an estimated 13 million per year.

Thus both estimates put walk diversion at 15% although they differed in terms of bus and car diversion.

Figure 4: Tenerife Tram

Photo by Frank Montgomery December 2018

Table 4: Before & After Study of Tenerife Tram

	Walk	Car	Bus	Tram	Total
Before Tram (2007)	14.1%	45.4%	40.5%	0.0%	100.0%
After Tram (2009)	8.8%	48.2%	9.5%	33.5%	100.0%
Change	-5.3%	2.8%	-31.0%	33.5%	0.0%
Set Car to Zero	5%	0%	31%	Na	36%
Source of Tram Demand	15%	-	85%	Na	100%

	Share in	2009 Choice				Source of
Mode	2007	Walk	Car	Bus	Tram	Tram Demand
Walk	14%	54%	13%	0%	35%	15%
Car	45%	3%	88%	2%	8%	11%
Bus	41%	0%	17%	22%	62%	74%

Based on figures presented in Gonzalez et al (2016)

A 1996 study of Manchester LRT, which connects two heavy rail stations (Piccadilly and Victoria) via on-street running and then runs on existing Altrincham and Bury rail lines, reported the source of LRT demand as 14% car, 27% bus and 59% rail, Oscar Faber (1996).[5] A ‘base case rail scenario’ estimated car diversion at 55%, bus 34%, rail 4%. An estimate by Knowles (1996) estimated the share of ‘not made’/other’ trips at 6%. Based on this estimate, walk diversion would be around 4%.[6]

[5] It was not possible to obtain the original reports for Manchester and Sheffield. The figures rely on a review by ITS: http://www.its.leeds.ac.uk/projects/konsult/private/level2/instruments/instrument002/l2_002c.htm

[6] If walk was half of ‘previously not made/other trips’ and if ‘not made trips’ were excluded (because the trips were not ‘diverted’) then walk’s share of diverted trips would have been around 4%.

A study of the Sheffield Supertram was undertaken in 2000 by WS Atkins.[7] The study aim was to explain the massive shortfall in patronage (the forecast had been 22.1 million trips but only 6.6 million materialised). In terms of diversion, 20% of Supertram patronage was sourced from car, 55% from bus and 12% from ‘other’ means. A further 12% was ‘new’ trips. If ‘other’ trips had been entirely walk and if ‘new’ trips are excluded then walk’s share would have been around 14%.

According to WS Atkins, a major reason for over-forecasting Sheffield LRT patronage was overestimating bus diversion (together with over-forecast demand from ‘new’ developments). Furthermore, instead of co-ordinating with LRT, bus companies competed for business. This issue was resolved when Stagecoach (which operated a significant proportion of bus services) took over the tram service. Thus the ‘lesson’ for walk diversion is that the level of diversion from bus and car partly determines the relative diversion from walk.

3.2 Second Best Alternative Surveys

The ‘source’ of demand can be estimated by asking Second Best Alternative (SBA) questions of the form: *“what would you have done if there was no rail service today?”*

Four surveys were undertaken in Australia in the early 2000s: SE Queensland 2001; Canberra 2003; Sydney Rail 2004 and Sydney CBD LRT 2004. Each is discussed in turn.

The 2001 South East Queensland study (undertaken as part of developing a transport demand scenario mode) estimated a walk share of 17% for bus passengers and 9% for rail passengers, Douglas, Frost and Franzmann (2003).[8]

A 2003 Canberra study to estimate bus fare elasticities included a SBA survey, BAH (2003).[9] The survey found that 12% of bus respondents would have walked had bus been unavailable and 15% would have cycled. The combined ‘non-mechanized’ share was 30% with not-travel excluded.[10]

RailCorp included an SBA question on a network wide ‘Value of Time’ onboard survey in 2004, Douglas Economics (2004).[11] For ‘short’ rail trips (<16 kms) trips, a distance category implying some seriously long walk trips! walk’s share was 10% in the peak and 9% in the off-peak.

In 2004, LRT, CBD rail and Inner West bus passengers were surveyed as part of forecasting patronage for a CBD extension, Booz (2004). 9% of peak and 14% of off-peak LRT respondents said they would have walked had LRT been unavailable. For CBD rail passengers, the walk share was 30% and for short bus trips it was 52% for

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[7] The Sheffield Supertram first operated on a 7km radial line out of the city centre. It was later extended to 22km after the opening of a second line.

[8] Walk was not separately reported but included amongst an ‘other’ category. However the authors did note that ‘other’ mainly comprised walk responses. A summary conference paper *“The Estimation of Demand Parameters for Primary Public Transport Service in Brisbane Attributes”* was presented by Douglas, Frost and Franzmann in 2003.

[9] *“ACT Transport Demand Elasticities Study”* by BAH & Douglas Economics to ACT Government 2003.

[10] Also shown, but not relevant for the LRT diversion factor are car and taxi responses. Car respondents were less likely to walk/cycle (19%) and more likely to use bus (67%). Taxi respondents were even less likely to walk or cycle with 89% saying they would use car or bus.

[11] *“Value of Rail Travel Time”* by Douglas Economics for Rail Corp Train Services dated May 2004.

the peak and 38% for the off-peak. The share dropped to 20% for bus trips longer than 20 minutes.

3.3 Model Forecasts of Walk Diversion to LRT

Demand forecasting models also provide an estimate of walk diversion. In 1995, BAH & Pacific Consulting prepared forecasts for extending the Pyrmont/Ultimo LRT to Circular Quay in Sydney.[12] Walk trips were estimated using an innovative *'moving observer'* technique for relevant zone pairs within the CBD (Central to Circular Quay and Darling Harbour to the Domain). Stated Preference surveys provided the evidence for the size of the diversion model parameters.

Figure 5 shows the walk versus PT market share for various origin-destination pairs. Superimposed is the predicted walk share which fell from 85% at 0.5 kms to zero at 3 kms. Equation 2 shows the model.[13]

$$\Pr(WALK) = \frac{\exp(3 - 2.5 * Distance)}{1 + \exp(3 - 2.5 * Distance)} \ldots\ldots(2)$$

Figure 5: Walk / PT (Bus+Rail) Share for travel within Sydney CBD travel (1995)

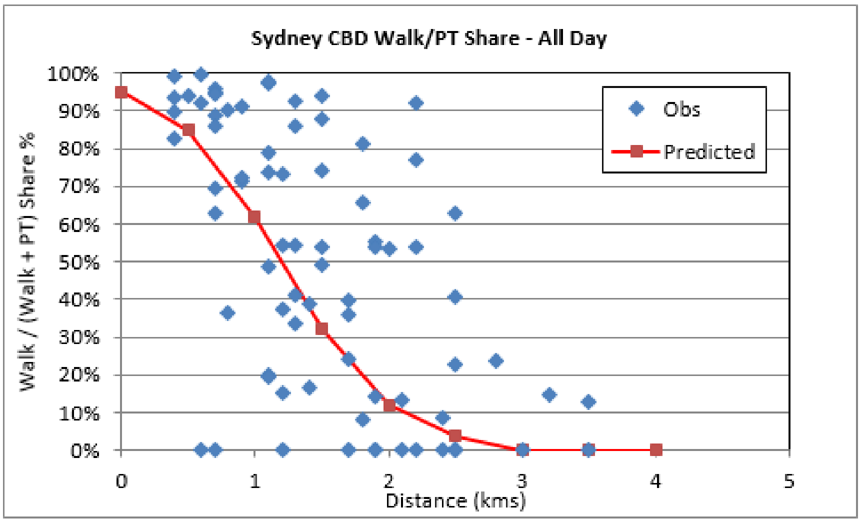

Table 5 gives the total market size (column 3) alongside the predicted walk and PT (bus + rail) shares (columns 4 and 5). The market size was highest between 0.5 and 1 kms with 39% of total intra CBD trips. Walk's share was 78%.

An incremental logit model pivoting on base shares (Equation 3) forecasts that LRT would increase PT share (bus + LRT) from 41% to 46% as shown in Table 5.[14]

$$\Pr(PTf) = \frac{\exp(-0.184\Delta V)(\Pr(PT))}{\exp(-0.184\Delta V)(\Pr(PT)) + \Pr(WALK)} \ldots\ldots(3)$$

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[12] *"Ultimo Pyrmont Light Rail Project CBD Extension Demand Study"* by Booz Allen & Hamilton and Pacific Consulting, report to NSW Department of Transport dated Sydney 22nd August 1995.

[13] The 3 km 'limit' in the equation reflected the study area. The average trip was 1.1 kms This average walk trip of 1.1 kms is therefore half the 2.3 km figure estimated by RAND for Sydney (see Table 1).

[14] Expressing the distance (KM) parameter (2.5) in equivalent PT minutes by dividing by the average walk speed of 4.5 kmh (estimated by the study) and dividing by a ratio of 3:1 for the disutility of walk time relative to PT time gives a PT IVT parameter of -0.18. The SP parameter of -0.14 implies either a slower walk speed or a higher disutility for walk relative to PT time.

Walk diversion to LRT (column 8) was forecast by multiplying the market size by the difference in PT share. Up to 0.5 kilometres, walk contributed 88% of diverted demand but dropped to 45% at distances of between 1 and 1.5 kilometres.

Table 5: Sydney CBD LRT, PT and Walk Shares 1995

Kms	2. Av Kms	3. Market Size	4. PT Share	5. Walk Share	6. PT mins	7. PT % with LRT	8. Walk Diversion	9. Walk Percent
< 0.5	0.4	13.1%	12%	88%	-0.8	13%	0.2%	3%
0.5 - 1	0.7	39.1%	22%	78%	-1.3	25%	1.3%	28%
1 - 1.5	1.2	26.3%	49%	51%	-2.3	57%	2.1%	45%
1.5 - 2	1.7	13.1%	77%	23%	-3.3	84%	0.9%	20%
2 - 2.5	2.2	4.3%	93%	7%	-4.3	96%	0.1%	3%
2.5 - 3	2.5	3.6%	96%	4%	-4.9	98%	0.1%	1%
> 3	3.1	0.5%	99%	1%	-6.0	100%	0.0%	0%
All	1.1	100%	41%	59%	-2.1	46%	5%	100%

Based on BAH/Pacific Consulting (1995)

Table 6 sets out the components of LRT demand. At 5%, the walk diversion rate (the proportion of walkers who divert to LRT) agrees with Table 5 (column 8) so with a base walk share of 59%, 14% of LRT demand would be sourced from walk. With induced demand excluded, the walk shares rises to 16%.

Table 6: Sydney CBD LRT and Walk Shares 1995

Transport Mode	Base Share	Diversion Rate to LRT	Patronage Source
Rail	12%	55%	32%
Bus	30%	30%	45%
Walk	59%	5%	14%
Induced	-	-	9%
Walk excluding induced demand	-	-	*16%*

Based on BAH/Pacific Consulting (1995)

Non-Sydney residents who made up a fifth of CBD trips when surveyed in 1995 (6% working plus 15% tourists) had a greater propensity to walk (see Appendix Table A5). Just under 50% were walking to cafes, bars, shops or to/from some other leisure activity (see Appendix Table A6). Company business accounted for 1 in 8 trips (three times as many as for rail or bus).

A forecasting study of extending LRT to Circular Quay was undertaken by BAH/Douglas Economics in 2004 (Appendix Table A5 presents the ‘intra CBD’ forecast for a George St alignment).

Walk’s share of the CBD market was 72% (compared to 59% in 1995) but diversion from walk was predicted at only 1% (compared to 5% in 1995)[15]. In combination, walk sourced 9% of LRT demand (compared to 16% in 1995).

In 2012, BAH and AECOM (2012) updated the 2004 study (see Appendix Table A6). Walk’s forecast share for 2021 was 75% (similar to 2004) with 5% diverting to LRT (higher than 2004 and the same as 1995) which sourced 13% of LRT demand.

[15] A cut-off of 500 metres was adopted for walk trips with trips less than 500 metres were considered non-divertible to LRT.

3.4 Summary of Walk Diversion Estimates

The eleven studies puts the likely walk share of LRT trips at 11% with a range from 4% to 16%, see Table 7.[16] The four 'before and after' (B/A) studies put walk diversion at 4% to 14%. The four 'second best alternative (SBA) surveys put the range at between 9% and 14%. The three Sydney LRT forecast models put walk diversion at between 10% and 16%. Thus, the three sources of evidence produced similar estimates of walk diversion.

Table 7: Estimated Diversion of Walk Trips to LRT as a Proportion of Total Diverted Trips

#	Study/Project	Approach	Walk Share	Comment
1	Croydon Tramlink 2002	B/A	4%	Detailed Home Interview panel survey. Long mixed route (on street and rail corridor sections) 0.7kms between stops.
2	Tenerife Spain 2007	B/A	14%	Survey of students (0.6kms/stop).
3	Manchester 1996	B/A	6%	Joined two rail corridors with on-street running. Estimate included 'other' trips so the estimate is a maximum.
4	Sheffield 2000	B/A	12%	Walk include in 'other' trips so a maximum estimate.
5	Sydney Rail 2004	SBA	10%	Estimate for short rail trips less than 4 kms.
6	Sydney LRT 2004	SBA	12%	Average of peak 9% and off-peak 14% for LRT users. CBD rail and short distance bus trips had walk shares of 29% and 45%.
7	Canberra 2003	SBA	12%	12% for bus respondents (excludes 15% cycling).
8	Brisbane 2001	SBA	14%	14% of bus respondents making short trips would walk; for rail, the percentage was 11%.
9	Sydney CBD LRT 1995	Model	16%	16% of LRT patronage was forecast to be sourced from walk.
10	Sydney CBD LRT 2004	Model	10%	10% of peak LRT patronage were sourced from walk.
11	Sydney CBD LRT 2012	Model	13%	13% of peak LRT patronage sourced from walk
	Average	-	11%	Range of 4% to 16%.

Notes: B/A before/after study; SBA survey of second best alternative of users, Model forecast

In actuality, the level of walk diversion will be context dependent reflecting whether the LRT service is street running or along a dedicated rail corridor (where walk diversion will tend to be lower). Diversion will also reflect the level of pedestrian activity, bus and train service level and how the public transport network is reorganized with LRT and what happens to car and taxi travel e.g. parking and pedestrianization.

With an 11% share, the factor that would be applied to diverted mechanized trips in PTPM would be 1.124, equation 4.

$$DIV_{ALL} = DIV_{MECH}\left(\frac{1}{1-\Pr(WALK)}\right) = DIV_{MECH}\left(\frac{1}{1-0.11)}\right) = DIV_{MECH}(1.124) \;\; \ldots .(4)$$

[16] Ingvardson & Nielsen (2018) provides a general discussion on the potential sources of LRT demand.

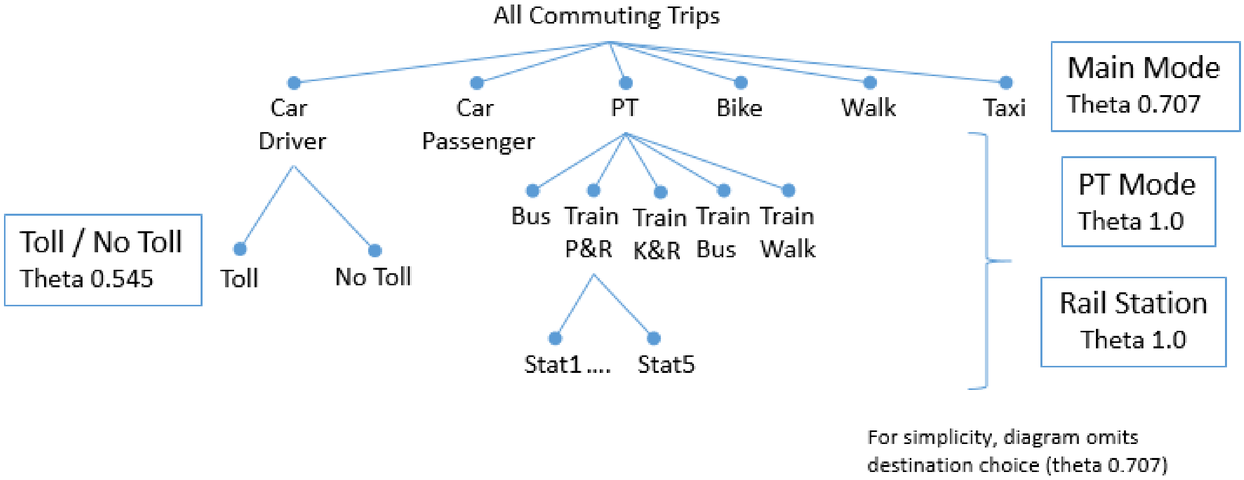
4 Forecast Walk Diversion

The Strategic Travel Model includes walk as a travel option which will be described in Section 4.1. Alternatively, a forecasting module could be added to PTPM by adding a choice 'branch' as will be explained in section 4.2 or by building a 'standalone' LRT v walk sub-model as will be shown in section 4.3.

4.1 Strategic Travel Model

Preliminary forecasts could be undertaken by STM. STM includes walk as a 'main mode' alongside car driver, car passenger, PT, bicycle, and taxi as shown in Figure 6.

Figure 6: Commuting to/from Work Mode Choice in STM3



Six main-modes are modelled at the top of the mode choice 'tree'. Public Transport (PT) is treated as a 'composite' mode. The theta parameter governing the sensitivity of mode choice with respect to generalised travel time is 0.707. Four different rail access modes are modelled with a higher theta value of 1.0 implying greater substitutability. LRT (and ferry) are treated as 'train' in terms of their parameters.[17]

There is no distance cut-off for walk or cycle trips as STM assumes that they are always available with Rand commenting that the *"predicted probability of choosing walk or bike for more distant destinations is extremely low".*

It is worth restating that STM is not used to forecast the demand for major public transport projects because of the errors in predicting base demand which is be a general problem of Four Stage Transport Demand Models and not a problem just specific to STM.

STM is used to project market size for PTPM by summing 'mechanized mode' trips (car, taxi, bus, rail, LRT and ferry.[18]

[17] Given that the theta parameter is 1.0 for both the PT mode and rail station choice, the choice structure collapses to a single level multinomial model. This contrasts with PTPM, where the choice of PT mode choice is less sensitive than rail access and station choice.

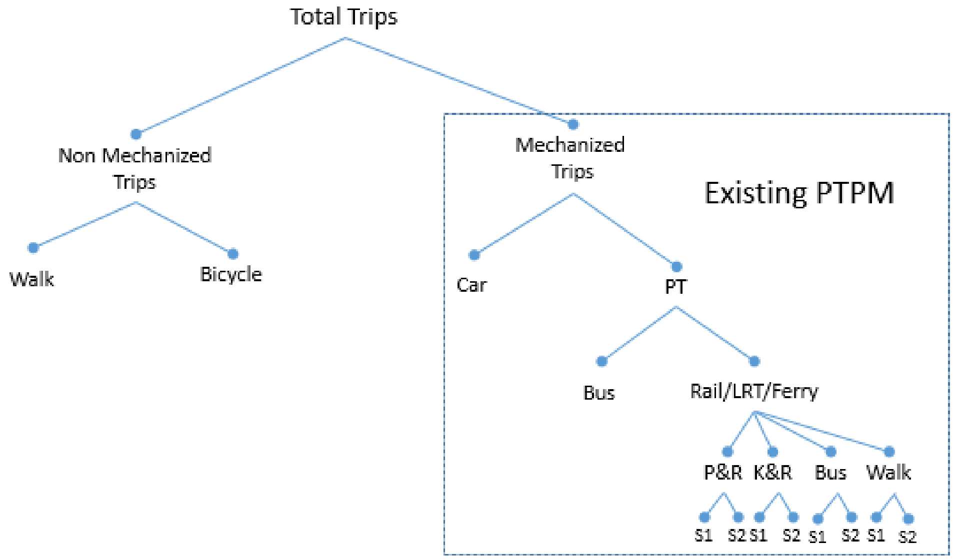
[18] Any diversion from walk (and bicycle) forecast by STM is included in 'with project' growth alongside redistributed trips. For simplicity, destination choice is not shown in Figure 6 and neither is trip frequency (induced demand). Given the calculation of mechanized trips is done for base and for future years, the difference is unlikely to be marked.

Given the STM choice structure, walk diversion to PT will be proportional to walk's base share.[19] A further difference between STM and PTPM is that STM models tours whereas PTPM models trips.[20]

4.2 Including Walk as an Additional Travel Model Choice in PTPM

Walk could be accommodated in PTPM as an additional 'non-mechanized travel' choice at the top of the PTPM mode choice tree as shown in Figure 7.[21] Accommodating walk in this way would allow the rest of PTPM to remain unchanged.

Figure 7: Including Non Mechanized Travel in PTPM



The approach has the advantage of not requiring walk trips, generalized times or alternative specific constants. These parameters could be deduced from the base shares given the size of the mode choice sensitivity parameter. Appendix B discusses this in more detail.

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[19] Until 2016, STM was not designed to forecast demand for intrazonal PT trips. There was no fare or service level information for PT trips made within a zone. TfNSW has developed a zone splitting module which works by production and attraction factors (population reflecting production and employment, and education enrolments reflecting attraction). A centroid connector is coded for each split zone which permits travel times and costs to be calculated for PT between the new zones and also to all other zones'. Intrazonal trips will still exist, but are smaller. There remains the choice of parameter values since the intrazonal constants for walk, cycle and car relate to un-split travel zones. STM forecasts walk and car trips for intrazonal trips but not PT trips. A zone splitting module has been developed to produce smaller zones and hence more inter-zonal trips that uses production and attraction factors (population measuring trip production with employment and student enrolments measuring attraction).

[20] This is relevant because HTS shows walk's share to be a third higher (19% v 14%) when calculated on a trip basis (PTPM) than on a tour basis. *Comparison of Trip and Tour Analysis of Sydney Household Travel Survey Data"* by Frank 'Frisbee' Milthorpe and John Daly, paper presented at ATRF Canberra 2010.

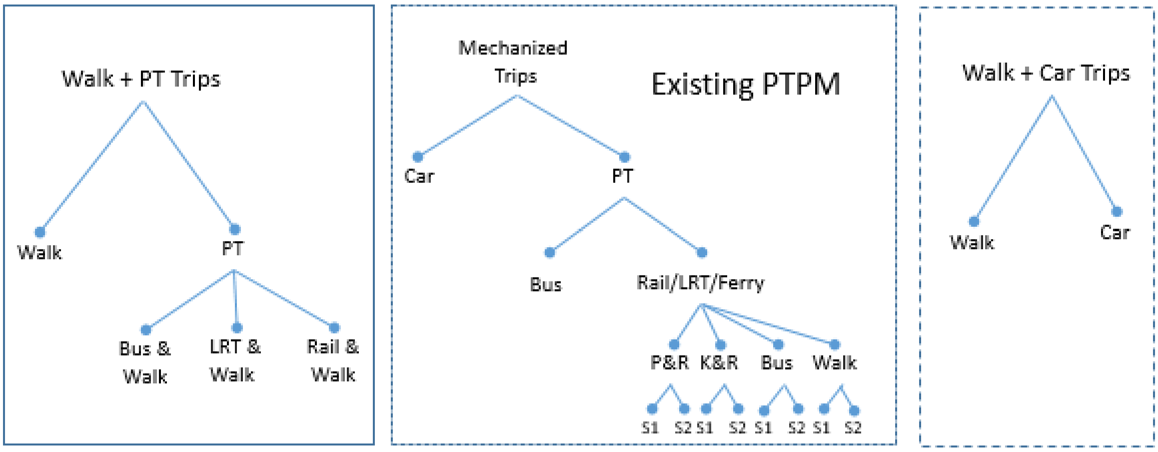
[21] 'Non Mechanised' travel could include bicycle and, if a split between walk and cycle is needed, it could be either proportional to observed base shares or some function of distance So long as PTPM is not used to forecast the impact of walk or cycling initiatives, walk and cycling shares can be assumed to remain unchanged. Alternatively, cycle could be omitted and assumed to be unaffected by the PT proposal.

4.3 Modelling Walk as a Standalone Pairwise Sub-Model in PTPM

Walk trips are only likely to divert to a new LRT service if the walk access and egress to the LRT stop is shorter than walking 'all the way'. This means a standalone walk v PT model could be kept simple. Only the closest LRT stop to a zone would need to be considered. Complicated car/bus access trips to multiple LRT stops can thus be omitted. The effect of introducing LRT on the PT/walk share could be assessed incrementally unless there is no 'current' PT service. Appendix C looks at an example OD pair.

Walk diversion could be modelled in PTPM as a standalone 'pairwise' walk versus PT choice as shown in the left hand box of Figure 8. For completeness, a walk v car model is shown in the dashed box on the right. This structure allows the existing mechanized mode choice model in PTPM to be retained unaltered.

Figure 8: Including Walk as a Standalone Sub-Model



One problem is determining the appropriate parameter values since most LRT studies have ignored walk diversion. Wardman reviewed ten UK Light Rail studies undertaken between 2001 and 2008 that included Stated Preference market research but none of the studies covered walk diversion.[22]

The 1995 and 2004 Sydney CBD LRT studies described in section 3 included walk as an option but only the 1995 study surveyed pedestrians.

The 1995 model adopted a hierarchical structure with PT v PT at the bottom and PT v Walk at the top.[23]

The GT_IVT parameter for PT v Walk was a third lower than in the PT v PT sub-model reflecting greater substitutability between PT modes than between PT and walk. The IVT parameter (PT v PT) was ten times larger than in PTPM (-0.38 versus -0.03) reflecting the short distance of trips and also its basis on stated rather than revealed preferences. The walk constant implied a 14 minute preference for walking over PT (time being expressed in on-board bus minutes).

[22] *"Support to UK Tram Activity 7 Work Group – benefits Involved in Appraisal Process – Analysis of Quantitative Research on Quality Attributes for Trams"* Report by ITS for UKTram Ltd dated April 2009.
[23] The estimated parameters are shown in Appendix Table A9.

Service interval (minutes between departures) had a relatively low valuation of 0.4 with walkers having the highest value of time ($12.90/hr) and bus respondents the lowest ($7.63/hr). Respondents preferred their own mode. Bus users preferred bus over rail by 1.9 minutes whereas rail users preferred rail over bus by 1.7 minutes. Walkers had a slight preference for rail over bus worth 0.4 minutes. Rail users preferred LRT to bus by 2.6 minutes. Walkers preferred LRT to bus by 1.6 minutes. Bus respondents were statistically indifferent between bus, rail and LRT.

The 2004 Sydney CBD LRT study included a travel choice model which valued walk 1.7 times more than PT onboard time (2.4 in the peak and 1.4 in the off-peak).[24] The constant for walking versus PT varied. Peak respondents strongly preferred walking (worth 16 minutes of PT time) whereas off-peak respondents were indifferent.

5 Conclusions

Based on a review of before and after studies, market research surveys and model forecasts, the share of LRT demand made up of former walkers is likely to be 11%. An initial forecast could therefore be achieved by multiplying predicted mechanized demand (bus, rail, car plus taxi trips) by 1.124.

Walkers are only likely to divert to a new LRT if the access/egress walk is shorter than their current walk. There is therefore no requirement to model complicated car/bus access trips to multiple stations. A ‘standalone’ LRT/Bus v Walk sub-model forecast incrementally where possible and absolutely where not should be adequate for most situations.

Our review identified a dearth of up-to-date survey data. The estimates of walk share were based on studies undertaken in the 1990s and early 2000s. This is despite the renaissance of Light Rail in Australia since 2010 with lines opened or extended in Adelaide, Canberra, Gold Cost, Newcastle and Sydney. Unfortunately there has been no published study of the composition of the LRT patronage.

The emphasis today is very much on big data with too little emphasis on surveying people. This is a pity and it is hoped that some surveys of LRT patronage in Australian cities will be commissioned in the near future.

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Any errors and omissions in the paper are the authors.

The views expressed are those of the authors and are not intended to represent those of Transport for NSW in any way.

[24] Appendix Table A10 presents the parameters.

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Appendix A: Survey & Model Estimates of Walk Diversion

Table A1: S.E. Queensland Transport Demand Scenario Model – Second Best Survey 2001

	Bus Respondents					Rail Respondents					Ferry	
	SPk	LPk	SOP	LOP	All^	SPk	LPk	SOP	LOP	All^	Pk	OP
Car	35%	54%	37%	57%	47%	42%	52%	52%	50%	51%	47%	41%
Bus	-	-	-	-	-	34%	16%	22%	19%	20%	19%	39%
Rail	18%	17%	19%	14%	17%	-	-	-	-	-	19%	9%
Ferry	12%	2%	14%	8%	9%	2%	0%	1%	0%	1%	-	-
Walk/Cycle^	11%	14%	20%	15%	15%	10%	3%	10%	3%	7%	11%	9%
Not Travel	24%	13%	10%	6%	12%	12%	29%	15%	27%	21%	4%	2%
*Walk/Cycle^^*	*14%*	*16%*	*22%*	*16%*	*17%*	*11%*	*4%*	*12%*	*4%*	*9%*	*11%*	*9%*

SPK Short (<30 minutes) Peak, LOP Long (>30 minutes) Off Peak
^ Walk/cycle was classified as 'other' in the study, ^^ excluding 'not travel'
Source: Douglas, Frost & Franzmann (2003)

Table A2: Canberra 2003 Fares Study - Second Best Survey

	Bus Respondents					**Car Respondents**				**Taxi**
SBA	**Work**	**School**	**Uni**	**Other**	**All***	**Work**	**Uni**	**Other**	**All***	**All**
Bus	-	-	-	-	-	84%	45%	59%	67%	45%
Car	57%	56%	43%	55%	55%	-	-	-	-	44%
Walk	10%	12%	9%	13%	12%	8%	0%	9%	9%	6%
Cycle	14%	15%	30%	11%	15%	4%	45%	19%	10%	2%
Taxi	19%	17%	16%	14%	16%	4%	0%	3%	8%	-
Not Travel	0%	0%	3%	7%	2%	0%	11%	9%	7%	3%
*Walk^*	*10%*	*12%*	*9%*	*14%*	*12%*	*8%*	*0%*	*10%*	*9%*	*6%*
Sample	69	63	74	81	287	81	67	76	224	71

^ Walk/cycle share with 'Not Travel' excluded
Source: BAH & Douglas Economics (2003)

Table A3: Sydney Rail - Second Best Alternative Survey (2004)

		Peak			**Off-Peak**				
	Short	**Med**	**Long**	**Short**	**Med**	**Long**	**Peak**	**Off Peak**	**All**
Rail Time mins	**<25**	**25-59**	**>59**	**<25**	**25-59**	**>59**			
Onboard kms	**<16**	**16-44**	**>44**	**<16**	**16-44**	**>44**			
Car	30%	42%	43%	21%	32%	35%	36%	27%	32%
Bus	43%	30%	19%	51%	36%	25%	35%	42%	38%
Walk/Cycle	9%	0%	0%	8%	0%	0%	5%	4%	5%
Taxi	4%	2%	1%	6%	4%	2%	3%	5%	4%
Not Travel	14%	26%	37%	14%	28%	38%	29%	31%	30%
*Walk/Cycle^*	*10%*	*0%*	*0%*	*9%*	*0%*	*0%*	*6%*	*5%*	*6%*
Sample Size	249	246	258	259	265	260	753	784	1,537

^ Walk/cycle share with 'Not Travel' excluded
Source: Douglas Economics (2004)

Table A4: Sydney CBD LRT Demand Forecasts - Second Best Survey

Mode	**Peak**				**Off-Peak**			
	LRT	**CBD**	**Bus**	**Bus**	**LRT**	**CBD**	**Bus**	**Bus**
Other PT	75%	47%	29%	47%	54%	53%	42%	39%
Car	6%	12%	10%	17%	12%	9%	8%	13%
Walk	9%	27%	49%	18%	12%	26%	36%	14%
Not Travel	0%	6%	6%	8%	10%	7%	7%	14%
Taxi/Other	10%	9%	5%	10%	12%	4%	7%	20%
*Walk^*	*9%*	*30%*	*52%*	*20%*	*14%*	*28%*	*38%*	*18%*
Sample	35	59	95	169	41	80	150	147

Bus short < 20 minutes; Bus Med > 20 minutes; CBD Rail trips made within Sydney CBD. ^ not travel responses excluded.
Source: BAH and Douglas Economics (2004)

Table A5: Residence of Walkers & PT Users in Sydney CBD (1995)

Respondent's Place Residence	Walk			Bus & Rail			
	Peak	Off Peak	All	Peak	Off Peak	All	All
Non Resident - Working	3%	11%	8%	6%	3%	4%	6%
Non Resident - Tourist	15%	18%	17%	9%	13%	12%	15%
Sydney Resident	82%	71%	75%	85%	84%	84%	79%
All	100%	100%	100%	100%	100%	100%	100%

Based on BAH/Pacific Consulting (1995)

Table A6: Trip Purpose of Walk & PT Users in Sydney CBD (1995)

Trip Purpose	Rail	Bus	Walk
Commuting	47%	22%	18%
To/from Education	9%	8%	3%
Company Business	3%	4%	12%
Personal Business	12%	13%	9%
Shopping	9%	20%	23%
Sightseeing	2%	8%	9%
Eating/Leisure	17%	24%	24%
Other	1%	1%	2%
All	100%	100%	100%

Based on BAH/Pacific Consulting (1995)

Table A7: Sydney CBD LRT Forecasts 2004

	Market Share				
Mode	Peak	Off-Peak	Week Day	Week End	Week
Bus	24%	16%	19%	30%	20%
Rail	10%	6%	7%	13%	8%
Walk	67%	77%	74%	57%	72%
Total	100%	100%	100%	100%	100%
	Forecast Diversion Percent to LRT				
Mode	Peak	Off-Peak	Week Day	Week End	Week
Bus	41%	35%	37%	25%	35%
Rail	28%	29%	29%	28%	28%
Walk	2%	1%	1%	1%	1%
Total	14%	8%	10%	12%	10%
	Forecast Source of LRT Demand Sydney CBD				
Mode	Peak	Off-Peak	Week Day	Week End	Week
Bus	71%	69%	70%	63%	69%
Rail	20%	22%	20%	32%	22%
Walk	10%	9%	10%	5%	9%
Total	100%	100%	100%	100%	100%

Source: BAH/Douglas Economics (2004)

Table A8: Sydney CBD LRT Forecasts for 2021

	Market Share				
Mode	Peak	Off-Peak	Week Day	Week End	Week
Bus	29%	25%	19%	19%	17%
Rail	13%	11%	8%	8%	7%
Walk	59%	64%	72%	73%	75%
Total	100%	100%	100%	100%	100%
	Diversion Rate Percent to LRT				
Mode	Peak	Off-Peak	Week Day	Week End	Week
Bus	46%	45%	43%	44%	39%
Rail	47%	48%	43%	45%	43%
Walk	5%	5%	3%	3%	2%
Total	22%	20%	14%	14%	11%
	Source of LRT Demand				
Mode	Peak	Off-Peak	Week Day	Week End	Week
Bus	60%	57%	59%	59%	59%
Rail	27%	27%	26%	26%	28%
Walk	13%	16%	15%	15%	13%
Total	100%	100%	100%	100%	100%

Source BAH/AECOM (2012)

Table A9: Sydney CBD LRT Extension - Estimated SP Parameters 1995 Study

Choice Level	Attribute	Respondent			
		Walk	**Bus**	**Rail**	**ALL**
Walk v PT Parameters	Walk Time	-0.14	-0.12	-0.14	-0.14
	Walk Constant	1.72	2.21	2.67	1.82
	PTGT	-0.12	-0.12	-0.20	-0.13
PT v PT Parameters	Rail Constant	0.14	-0.91	0.66	0.03
	LRT Constant	0.59	-0.01	1.00	0.54
	Service Interval	-0.14	-0.26	-0.20	-0.15
	Fare	-1.69	-3.74	-2.30	-1.97
	IVT	-0.36	-0.48	-0.38	-0.38
Walk v PT Values	Walk / PTGT	1.2	1.0	0.7	1.1
	Walk Constant / PTGT	-14.3	-18.4	-13.4	-14.0
PT v PT Values (IVT mins)	Rail v Bus Constant /IVT	-0.38	1.90	-1.72	-0.16
	LRT v Bus Constant / IVT	-1.63	0.01	-2.61	-1.47
	SI / IVT	0.37	0.54	0.53	0.40
	60*IVT/Fare ($/hr)	12.90	7.68	10.02	12.13

Source BAH Pacific Consulting (1995)

Table A10: Sydney CBD LRT Walk v PT Model – 2004 Study

Parameter	**Peak**	**Off-Peak**	**All**
PT GT	-0.10	-0.09	-0.09
Walk Mins	-0.23	-0.12	-0.16
Constant	-1.52	0.09	-0.47
Walk/PT_GT mins	2.4	1.4	1.7
Constant/IVT mins^	15.7	-1.0	5.0

^ positive constant value indicates a preference for PT, -ve for walk
Source: BAH/Douglas Economics (2004)

Appendix B: Formulae for introducing a walk 'branch' into PTPM

Figure B shows a PT project that improves generalized time from 50 to 40 minutes. Base demand is 100 trips split 30 PT, 60 car and 10 walk.

Including walk as branch in PTPM would have the effect of reducing diversion from car.[25]

Figure B: Including Walk in an Incremental Model

Total Trips	Base	New	Change
Trips	100	100	0.0
Comp GC	8.4	5.0	-3.3

Source of PT Change	Trips	Share
Walk/Cycle	0.7	10%
Car	5.9	90%
Total	6.5	100%

Non Mechanised (Walk/Cycle)	Base	New	Change
Trips	10	9.3	-0.7
Share	10%	9%	
Implied GT	118.0	118.0	0.0

Mechanised Trips	Base	New	Change
Trips	90	90.7	0.7
Share	90%	91%	
Comp GC	13.4	9.7	-3.7
Theta		0.7	
Theta * Lambda		-0.021	

0.7

Car	Base	New	Change
Trips	60.0	54.1	-5.9
Share	67%	60%	
Implied GT	26.9	26.9	0.0

Public Transport	Base	New	Change	% Chng
Trips	30.0	36.5	6.5	22%
Share	33%	40%		
Gen Time	50	40	-10	-20%
Lambda		-0.03		

For PT v car, the reduction of 10 minutes in PT GT increases the PT share from 33% to 40% with a sensitivity parameter (λ) of -0.03.

$$PrPT' = \frac{\exp(\lambda\Delta PTGT)\text{ x PrPT}}{\exp(\lambda\Delta PTGT)\text{ x PrPT} + \text{PrCAR}} = \frac{(\exp(-0.03\times -10))\times 0.33}{(\exp(-0.03)\times -10)\times 0.33 + (0.67)} = 0.4$$

The base composite 'log sum' cost for mechanized trips is 13.4 minutes in rail time minutes:

$$MGT = \frac{1}{\lambda}\ln\{(exp\lambda PTGT) + exp\lambda CARGT) = \frac{1}{\lambda}\ln\{(\exp\big(-0.03(50)\big) +$$
$$\exp\big(-0.03(26.9)\big) = 13.4 \text{ where:}$$
$$CARGT = PTGT + \frac{1}{\lambda} ln\frac{PrCAR}{PrPT} = 100 + \frac{1}{-0.03} ln\frac{0.67}{0.33} = 26.9$$

Likewise, the new generalized mechanized trip composite cost(MGT') is 9.7 minutes a reduction of 3.7 minutes.

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[25] Therefore if walk had been included in this way within previous projects, despite the forecast total diversion increasing, car diversion would actually have been lower. Since car diversion has an externality benefit whereas walk diversion is most likely to have an externality cost (reduced health benefits), the inclusion of walk in PTPM would probably have reduced forecast project benefit.

Combining the reduction in mechanized trip composite cost of 3.7 minutes with the base mechanized trip share of 90% and walk share of 10% and the mode share sensitivity lambda ($\lambda w = -0.021$) a forecast mechanized trip share of 91%.

$$PrM' = \frac{\exp(\lambda w \Delta \mathrm{M}GT)\ \mathrm{x\ PrM}}{\exp(\lambda w \Delta \mathrm{M}GT)\ \mathrm{x\ PrM} + \mathrm{PrWALK}} = \frac{(\exp(-0.021 \times -3.7)) \times 0.9}{(\exp(-0.021) \times -3.7) \times 0.9 + (0.1)} = 0.91$$

Applying these proportions to the trip volumes gives an increase in PT share of 6.5 trips of which 5.9 trips (90%) are sourced from car and 0.7 (10%) from walk. Thus adopting this approach so long as base shares and the base PT generalised cost is known, the other times and costs are internally calculable.

STM calculates walk disutility according to distance. The parameter for commuting trips is -1.169. Assuming a walk speed of 4.5kph (based on an Ultimo-CBD study by Booz et al in 1995) the equivalent walk time parameter would be -0.097. The disutility of walk time per minute is therefore around three times that of onboard PT time.

The model reduces to a multinomial if the sensitivity between mechanized and non-mechanized travel is assumed to be the same as that between PT and car. Diversion will be proportional to the base shares (lambda being the same as for PT v car). This would mean that PTPM has the same model structure as STM (for commuting to work).

The sensitivity parameter for PT v Car for commuting and business trips in PTPM version 5 was set at -0.03. For education and other trips it was set at -0.02. If choice sensitivity is reduced at the ‘top of the tree’ to model walk v PT then sensitivity parameters of -0.02 and -0.01 for commuting/business and education/other trips would be reasonable.

Appendix C: Modelling Walk as a Standalone Pairwise Sub-Model

The generalized times and trips have been set to be the same for the walk branch option (Appendix B).

The sensitivity parameter is also the same (-0.03).

The PT v Car model gives the same result as Figure B, an increase of 6.3 trips but walk diversion is larger at 2.1 trips (compared to 0.9 and 0.7 trips). This is because the change in Generalised Time is greater when car is omitted.

Figure C: Including Walk as a Pairwise Model

Mode	Base	PT v Car	PT v Walk	Car v Walk	Total	New %
PT	30	6.3	2.1	na	8.3	38.3
Walk	10	na	-2.1	0.0	-2.1	7.9
Car	60	-6.3	na	0.0	-6.3	53.7
Total	100	Car	Walk			100
PT Source		75%	25%			

	PT v Walk		
	PT	Walk	Total
Base Trips	30	10	40
Base Share	75%	25%	
Base GT	50	86.62	13.38
New GT	40	86.62	
New Shares	80%	20%	
Trips	32.1	7.9	40.0
Change	2.1	-2.1	0.0
Lambda	-0.03		

Existing PTPM			
	Car v PT		
	Car	PT	Total
Base Trips	60	30	90
Base Share	67%	33%	
Base GT	26.9	50	13.4
New GT	26.9	40	
New Shares	60%	40%	
Trips	53.7	36.3	90.0
Change	-6.3	6.3	0.0
Lambda	-0.03		

	Car v Walk		
	Car	Walk	Total
Base Trips	60	10	70
Base Share	86%	14%	
Base GT	26.9	86.62	21.8
New GT	26.9	86.62	
New Shares	86%	14%	
New Trips	60.0	10.0	70.0
Change	0.0	0.0	0.0
Lambda	-0.03		
New Trips	53.7	7.9	61.7
New Share	87%	13%	