Australasian Transport Research Forum 2013 Proceedings
2 - 4 October 2013, Brisbane, Australia
Publication website: http://www.patrec.org/atrf.aspx

Analysis and planning of bicycle parking for transport interchanges

David Arbis, Dr. Taha Rashidi, Dr. Vinayak V Dixit, Dr. Upali Vandebona

School of Civil and Environmental Engineering
University of New South Wales
Sydney, NSW 2052
Email for correspondence: d.arbis@unsw.edu.au

Abstract

Guidelines for providing bicycle parking at transport interchanges in Australia remain inadequate to ensure patronage. The inadequacy stems from the generic as opposed to definitive guidance on the location of bicycle parking spaces and selection between bicycle parking devices. This generic guidance is incapable of addressing the local needs of individual stations. Therefore what is proposed is a segmentation study of observed bicycle parking behaviour, where subgroups of parked bicycles are used to explain parking preferences in a more specific manner useful for heterogeneously implementing bicycle parking at different stations. The study finds that significant parking behaviour differences exist between bicycles parked at different sized stations and also between bicycles parked at different classes of parking devices. This has implications on the placement and selection of bicycle parking infrastructure at transport interchanges.

Data was collected through counts of parked bicycles at thirteen of Sydney's (Australia) West and Inner-West railway stations, varying in size from small to major transport hubs. Parking distances to station entrances were recorded along with streetscape features surrounding parking locations. Further, patronage data of the NSW Government's secure bicycle locker devices was collected to allow comparison of parking patterns between bicycles parked in secure infrastructure to those parked outside in the open-air.

1. Introduction

Integrating bicycles and transit through bicycle parking brings among all, economic, environmental and social benefits to communities. This is achieved through expediting a shift from car use to bicycles and transit. Bicycle-transit is a time competitive alternative to unimodal car travel directly to destinations (Martens, 2007) as well as car travel to transit interchanges (Martin, 2010). Standing evidence of this time-competitiveness lies in the significant proportion of bicycle parkers replacing their car trips with bicycle-transit in Australia (Martin & den Hollander, 2009; Parker, 2002; Third Wave Cycling Group Inc. et al., 2010) and the international context (Martens, 2007) after provision of bicycle parking spaces. Bicycle parking is also a more space-efficient, cheaper alternative to car parking for attracting transit patronage (Martin, 2010).

However, when bicycle parking facilities are provided at transit interchanges, especially in the Australian context, they are not necessarily utilised. For example, open-air bicycle parking facilities provided in Sydney (Australia) public transport interchanges are found with scattered occupancy levels, without an alignment with predictors such as parking distance and estimated bicycle security (Lehman et al., 2009). Also, secure enclosed bicycle locker facilities provided by the New South Wales Government hold a mean lease rate of 42% with a standard deviation of 34% (NSW Government, 2013). Bicycle parking enclosures called "Bike Stations" implemented in the San Francisco Bay Area likewise experience widely dissimilar utilisation, ranging from 11% to 100% (Pucher & Buehler, 2009).

There have been several efforts to predict latent demand for bicycle parking facilities so that when facilities are provided, they are utilised. These are the studies of Bachand-Marleau et al. (2011), Chen et al. (2012), Keijer & Reitveld (1999), Lehman et al. (2009), Martens (2004), Martin & den Hollander (2009) and Reitveld (2000), which have examined seminal traveller and urban form attributes. However despite these efforts, there still stands significant barriers to realising bicycle parking usage and hence the benefits arising from usage. For one, private bicycles left at an interchange face the possibility of theft and vandalism, which has been a significant deterrent to bicycle parking (Austroads, 2008; Martin & den Hollander, 2010; Parker, 2002; Parker, 1992; Pucher & Buehler 2009). It has also been shown that excessive walking access distances from parking spots to interchange entrances encourage uptake of station access modes other than cycling (Chen et al., 2012).

Therefore a study is necessary to counter these barriers, and it is considered fitting by the authors to address them through investigating suitable siting of bicycle parking spaces and selection between appropriate bicycle parking devices for interchanges. With suitable siting of spaces and selection between appropriate bicycle parking devices, a reduction in bicycle theft, walking access distances and ultimately a realisation of latent demand for bicycle parking may be achieved. This is what this study investigates: a method to provide insight for suitable siting of bicycle parking spaces and selection between bicycle parking devices.

Available literature provides coarse qualitative and empirical advice for siting of bicycle parking spaces and selecting between classes of bicycle parking devices for transport interchanges. Such advice has a 'bulk-of-evidence' nature, which is unable to cater for the requirements of all interchanges.

Generic suggestions for siting bicycle parking spaces at interchanges are provided by Austroads (2008). Among all, Austroads suggests bicycle parking devices be placed in public view and as close as possible to destinations, within 100m distance. Similarly Martin & den Hollander (2010; p. 13), present a set of rules employed for siting Melbourne's 'Parkiteer' bicycle parking cages which includes: "Cages should be located close to the entry/exit of the station. This provides quick arrival and departure by cyclists and also good passive surveillance against vandalism and theft". It is evident available siting principles lack a level of precision to definitively guide infrastructure implementation.

In terms of selecting between classes of bicycle parking devices to implement at interchanges, Austroads (2008) suggests taking into account an interchange's level of surveillance against bicycle theft and vandalism. This surveillance refers to passive surveillance from passing pedestrians and active surveillance from station staff. Secure bicycle lockers are recommended when there is low surveillance and where there is significant surveillance, open-air bicycle racks are regarded suitable. Hence there is some guidance to select between bicycle parking devices based on bicycle surveillance. What the advice lacks however is it does not make clear what constitutes a level of bicycle surveillance. It would be useful if there was a significant proxy variable(s) determined useful to delineate between different levels of bicycle surveillance. The study presented in this paper investigates this.

The study methodology is set out as follows. The 'Field Surveys' section gives details on the surveys that were performed and data collected for this study. The 'Analysis' section segregates collected data into various interchange and parking device populations to show differences in bicycle parking siting preferences between populations. A predictive analysis is included to investigate the bearing of specific streetscape features indicative to where cyclists site their bicycles in the open-air. The 'Analysis' section also includes a diurnal study of open-air bicycle parking at interchanges. Literature currently presents only two such intra-day studies at interchanges performed in Nanjing, China (Chen et al., 2012). A diurnal study is performed as part of this research to investigate diurnal patterns of demand and support previous findings.

The final section of the research work provides concluding remarks regarding the methodology followed and possible implications for bicycle parking provision.

2. Field surveys

Observations of were made of current bicycle parking behaviour (revealed preference). Data of current behaviour was used in the research because it does not control for bicycle theft, vandalism and walking access distance constraints. Considering aims of the paper being the investigation of suitable placement of bicycle parking facilities and choosing between types of bicycle parking device to combat these constraints, revealed preference data was deemed fitting.

2.1 Open-air bicycle parking

Attributes of sites where cyclists prefer to park their bicycles were observed. These sites encompassed all open-air bicycle parking, comprising bicycles at provided bicycle racks and at street furniture such as fences and street poles. Bicycle parking sites were observed at thirteen differently sized train stations (according to passenger volumes, of which train service frequency was used a surrogate measure) running along the Sydney suburban railway network.

These surveys started at Blacktown train station in Sydney's West and continued along Western Line stations to Strathfield train station in the Inner-West. A total of five surveys were conducted on five separate weekdays, with each station visited once during each survey day by travelling from station to station in sequence.

About half-an-hour was allowed for inspection of bicycle parking near one station and to travel to the next station. Each survey day thusly took a total of 6 hours. The first survey day started at 09:30 and two subsequent surveys started at 10:30 and 11:30 respectively (staggered by one hour) to counter to an extent the effect of diurnal bicycle parking patterns. One survey commenced at 09:30 and was conducted in the reverse direction to further counter diurnal patterns.

The sites where bicycles were parked within 150m walking distance to station entrances were included in the survey. Each site was defined by its parking distance rounded to the nearest 5m and the streetscape parking amenity features surrounding the site. For every observed site, the parking distance to the nearest station entrance was recorded in-situ, rounded to the nearest 5 metres. Sites where bicycles were found parked within station walkways and concourses were allocated a distance value of 0m. Streetscape parking amenity features surrounding parking sites were also recorded. These amenity features recorded in the surveys were predetermined in a list and included among all, shelter, CCTV (Closed Circuit Television) cameras, appropriate lighting, bus stops and shops. This list of amenity features has previously been used in a bicycle parking study (Lehman et al., 2009). A comprehensive list of the features is listed as part of Table 3 in the analysis section of the paper.

Some observed bicycle parking sites were eliminated from the collected sample under suspicion they did not represent bicycles involved in bicycle-transit trips. Parking distance was used as a factor to objectively guide elimination from the sample. Parking sites at a distance with a z-score greater than three was used as a guide, corresponding approximately to bicycles parked at further than 100m from station entrances. Hence all sites with bicycles parked further than 100m were eliminated from the sample (n=14 bicycles, 2.7% of the sample bicycles), under the notion bicycles at these sites were not parked for bicycle-transit. This is coincidentally concurrent with Austroads' (2008) recommendation that bicycle parking facilities should be located within 100m from stations.

After removal of outliers, on average there were 104.8 bicycles counted in a survey day (a total of 524 bicycles over the five days), with 42% observed parked formally at provided parking spaces. The other 58% were observed generally attached to street furniture. As for bicycle parking sites, over the five survey days there were 62 bicycle sites observed with an average and standard deviation of 1.7 and 2.5 bicycles per site. These apparently low bicycle numbers per site are partially due to some sites being irregularly active.

2.2 Secure bicycle parking

Patronage and parking distance data of secure bicycle parking devices was collected to show parking patterns for this subset of bicycle parking and make comparisons with the patterns of open-air bicycle parking.

Lease rates of secure bicycle locker assemblages provided at NSW transit interchanges by the NSW Government were determined through the official bicycle locker website (NSW Government, 2013). Also using this website, all 130 bicycle locker assemblages at train stations were geographically located and parking distances to station entrances were measured**.** On May 26th 2011, 1066 bicycle lockers were provided at train interchanges with 506 lockers reported leased.

2.3 Intra-day variations

Diurnal observations of open-air bicycle parking were made at a train station with a relatively high volume of bicycle parking (Lidcombe train station, situated in Sydney's Inner-West). The observations were made to infer trip purposes for open-air bicycle parking and diurnal patterns of demand. Commuter car parking at the train station was observed at the same time to compare the two vehicle groups and infer if trip purposes for open-air bicycle parking were aligned with commuter car parking.

Both bicycle and car parking were observed at Lidcombe train station on 2nd August 2011 for a period of twelve hours from 07:00 to 19:00. An inventory count of parking spots at bicycle racks and the station commuter car park showed a capacity of 19 provided bicycle spaces and 153 car spaces.

Hourly photographs were taken of all bicycles parked within 150m walking distance of station entrances from 07:00 to 19:00. The arrival and departure times of parked bicycles were approximated by inspection of photographs, coinciding with a photography method discussed by Moskovitz & Wheeler (2011). At the same time, the patronage of the nearby commuter car park was simultaneously documented by manual count.

A total of 44 parked bicycles were observed in the survey time period.

3. Analysis

The analysis section presents results in three parts. The first part shows results of intra-day patterns of bicycle parking. The second part details where bicycle parkers prefer to site their bicycles defined by parking distance, and how different interchanges and parking devices are characteristic of different parking distances. The last part further expands upon the bicycle siting findings by identifying important predictors for siting open-air bicycle parking through regression and data mining approaches.

3.1 Intra-day variations

In this part, results are presented of the diurnal pattern of bicycle parking and a comparison of bicycle parking against car parking. These were observed through the intra-day survey. Graphical plots and descriptive statistics are used in the analysis.

A total sample of 44 parked bicycles was observed in the survey time period. At the beginning of the survey (07:00), there were already 20 bicycles found at the interchange and at the end of the survey (19:00) 15 bicycles remained. Of the 15 bicycles remaining parked after the survey, 7 had been parked for over 12 hours, 4 had been parked for 10-12 hours and 4 for less than 10 hours. Within the latter 4, 2 had been parked for less than an hour due to late arrival between 18:00 and 19:00.

A parking duration frequency plot was formed to show a distribution of bicycle parking durations. The plot was formed from parking duration data obtained from 42 of the 44 sample bicycles, where the two bicycle arrivals between 18:00 and 19:00 were rejected. It is evident from this plot (Figure 1) there is a skew for parking durations to exceed 8 hours. Almost 70% of bicycles were parked for longer than 8 hours.

Figure 1: Distribution of bicycle parking durations

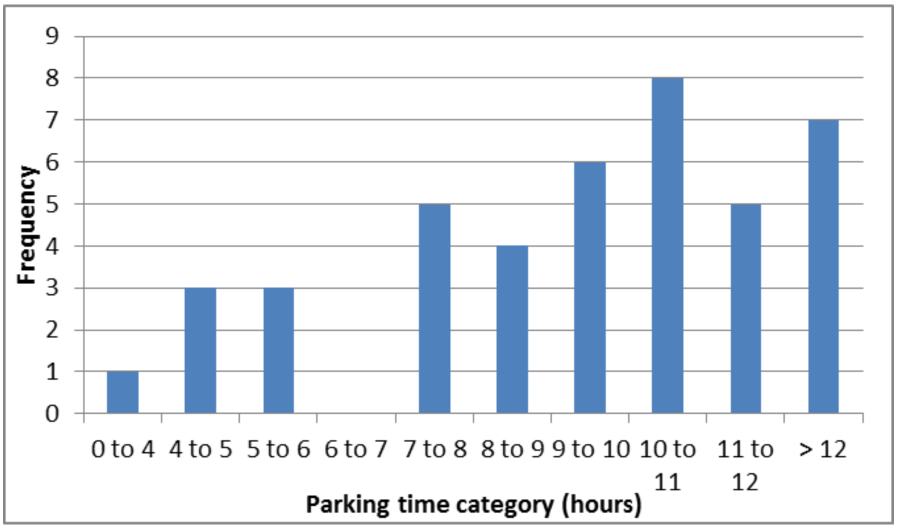
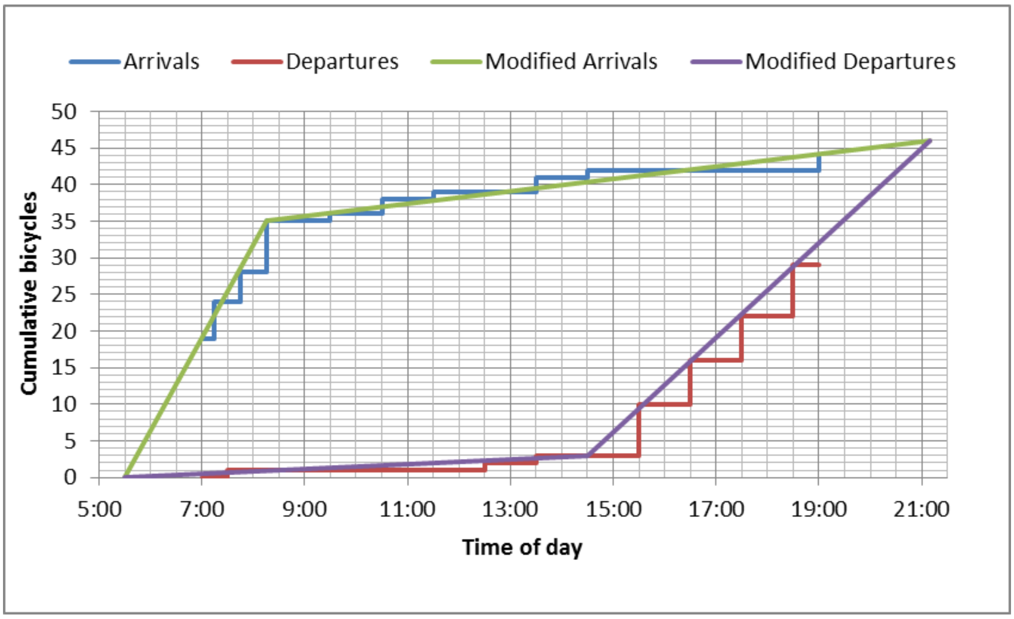


Figure 2: Bicycle arrival and departure curves



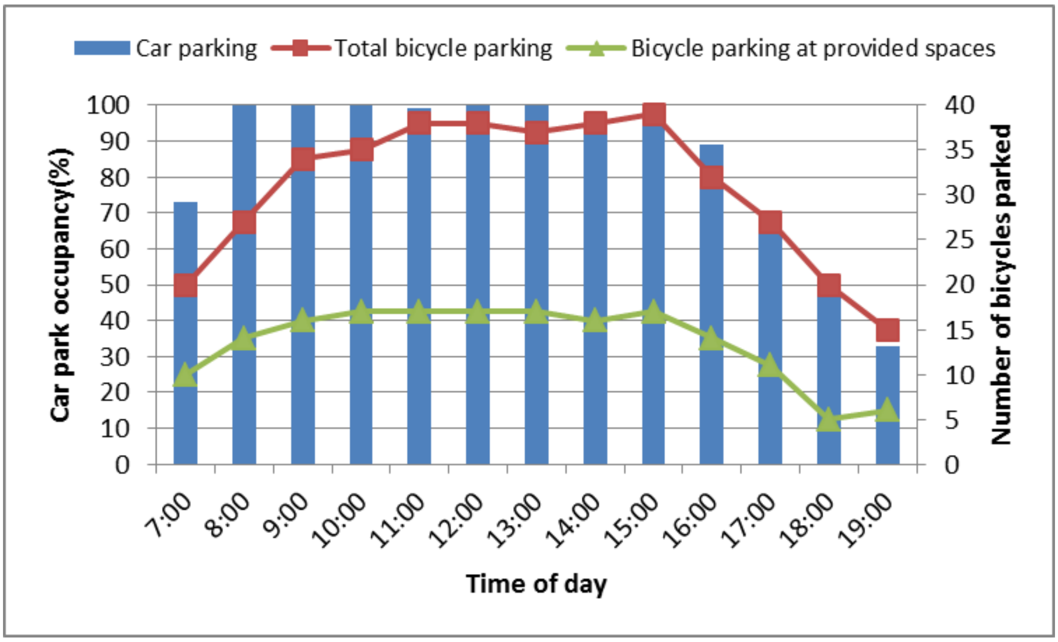
A mean bicycle parking duration is calculated at 9.1 hours with a standard deviation of 2.8 hours. However these values assume all bicycles started to park at 07:00 and left at 19:00 which is not the case. There were 20 bicycles which had been parked before 07:00 and 15 bicycles remaining after 19:00. In order to account for this and extrapolate a true mean bicycle parking duration, modified parking arrival and departure curves were developed by tracing over gradients of actual arrival and departure curves. These modified curves are shown in Figure 2. By calculating the area encapsulated in between the modified plots, an extrapolated mean bicycle parking duration was derived at 8.5 hours.

The modified arrival and departure curves based on tracing over gradients of actual arrival and departures curves also extrapolate a time for the first bicycle arrival at the station and the last bicycle departure. The first bicycle is extrapolated to arrive at the interchange at approximately 05:30 and the last bicycle leaves 21:00. This coincides with results of a diurnal bicycle parking study conducted at Longmian Road Station in Nanjing, China where the last bicycle similarly left by 21:00 (Chen et al., 2012).

Graphical comparison of bicycle parking against car parking during the survey day (shown in Figure 3) indicates the intra-day patronage pattern of the two vehicle groups coincide, especially the departure portions after 15:00. The arrival portions have less accord because of the capacity-limited nature of car parking as opposed to the non-capacity limited nature of bicycle parking at street furniture. Overall, the significant intra-day accord of bicycle parking and commuter car parking illustrated in Figure 3 supports through observed behaviour that trip purposes for bicycle parking and commuting car parking are the same.

The graphical comparison of Figure 3 also illustrates the uptake of provided bicycle parking spaces. All the bicycle parking spaces are placed within 25m proximity to station entrances, collectively operating at almost full capacity from 10:00 to 15:00. Despite being closely located to the station entrances, it is evident there are still bicycle parkers who prefer not to use them and to park at street furniture (such as fences and sign poles) even when there are spaces available before 10:00. This agrees with a previous study where it is also indicated some bicycle parkers find formally provided bicycle parking spaces to be undesirable in comparison to street furniture (Lehman et al., 2009).

Figure 3: Daily fluctuation of bicycles and cars parked at Lidcombe train station



3.2 Bicycle parking distances

To show differences in bicycle parking distances across interchanges and across classes of bicycle parking devices, subgroups of bicycles were formed from the collected data based on train service frequency of interchanges and class of parking device. Data on train service frequency of interchanges was collected through the NSW Rail Corporation (2013). Four bicycle parking subgroups were formed – open-air bicycles at stations with hourly services < 15 in the a.m. peak, open-air bicycles at stations with hourly services >30 in the a.m. peak, open-air bicycles at all surveyed stations and bicycles parked in secure bicycle lockers.

Cumulative percentile plots, descriptive statistics and two-group mean t-tests were used in the analysis to make parking distance comparisons between these formed subgroups.

Cumulative percentile plots were drawn to find any threshold distances from station entrances where bicycle parking levels started to decline. Amongst bicycles parked in the open-air, a threshold distance where bicycle parking declined occurred at seemingly close distance to station entrances, within 30m. The subgroup of open-air bicycles at stations with hourly services <15 in the a.m. peak were found with a smaller threshold parking distance than open-air bicycles at stations with hourly services >30 in the a.m. peak. The threshold distance values were 13.3m and 26m respectively. This could indicate bicycle parkers at less-busy stations prefer to park close to station entrances so that their bicycles can be seen by passing station passengers and station staff, whereas those at busier interchanges need not park so close to be seen. This idea is further supported with 20% of open-air bicycles at stations with hourly services <15 in the a.m. peak found parked within station walkways and for stations with hourly services >30 in the a.m. peak this value lies at 6%. The cumulative percentile plots are shown in Figures 4 and 5.

The above paragraph thusly provides some information about preferences to site bicycles, and also indicates the suitability of interchange service frequency to be a proxy variable for surveillance against bicycle theft and vandalism. A greater service frequency could mean greater people traffic, and hence greater bicycle surveillance. Interchange service frequency could thus be a delineator decision makers can use to decide whether it is necessary to implement secure parking devices such as bicycle lockers or not.

Open-air bicycle parking occurs at a much closer proximity to station entrances than parking in secure bicycle lockers as shown in the cumulative percentile plots in Figure 5. The initial gradient of the curve representing bicycle locker patronage is less steep than the initial gradient of the curve representing open-air bicycles, indicating open-air bicycle parking decreases relatively rapidly with distance. This difference could mean there is a relationship between bicycle security of bicycle parking devices and bicycle parking distance. This is whereby open-air bicycles, in order to be seen by passing pedestrians must be parked in proximity to station approaches whereas bicycle lockers, inherently providing bicycle security against theft and vandalism, do not. The difference in parking patterns between these two groups also indicates that secure bicycle parking devices can be placed away from congested interchange pathways and still encourage bicycle parking patronage, unlike open-air bicycle parking.

Figure 4: Cumulative percentile distribution of parked bicycles by bicycle parking subgroups

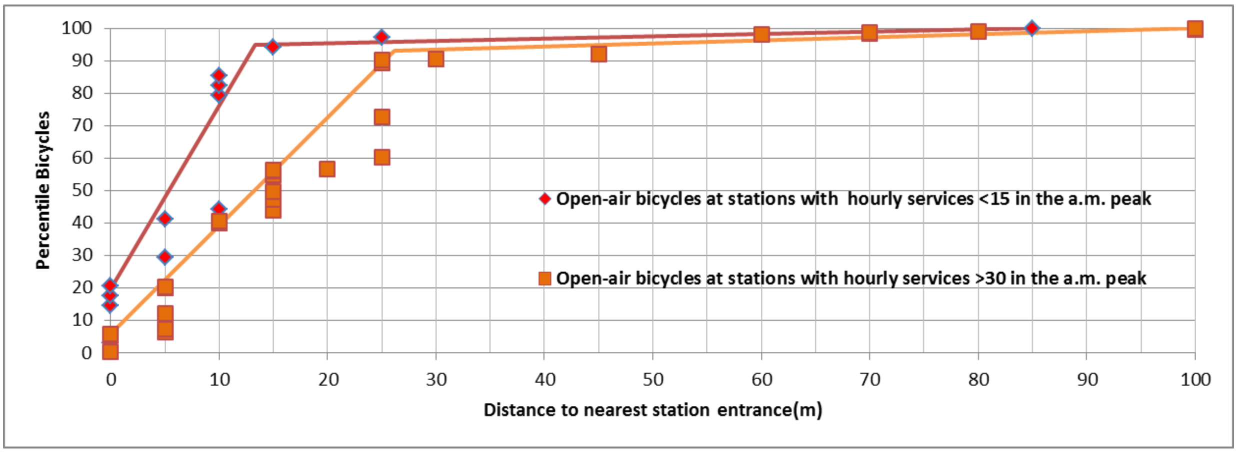


Figure 5: Cumulative percentile distribution of parked bicycles by bicycle parking subgroups

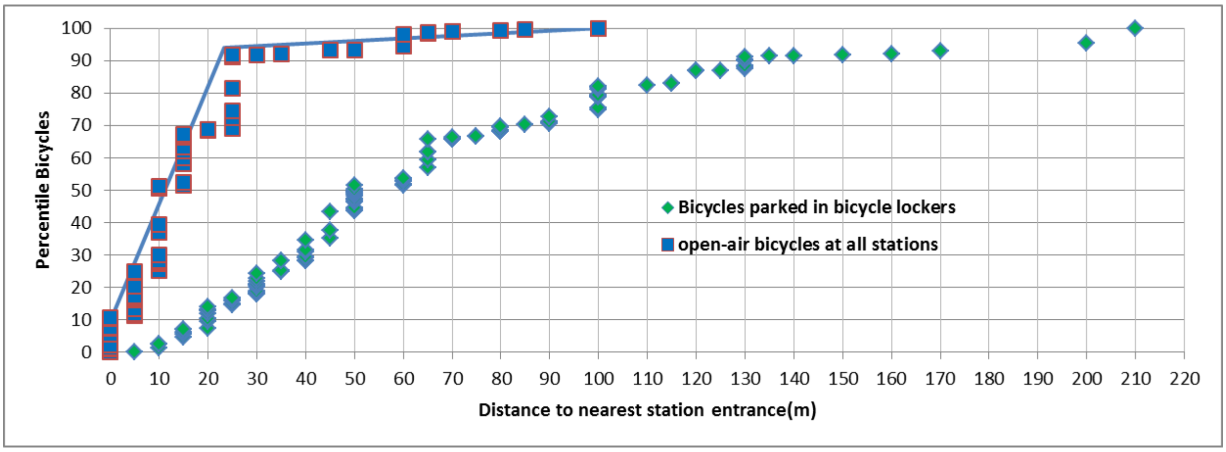
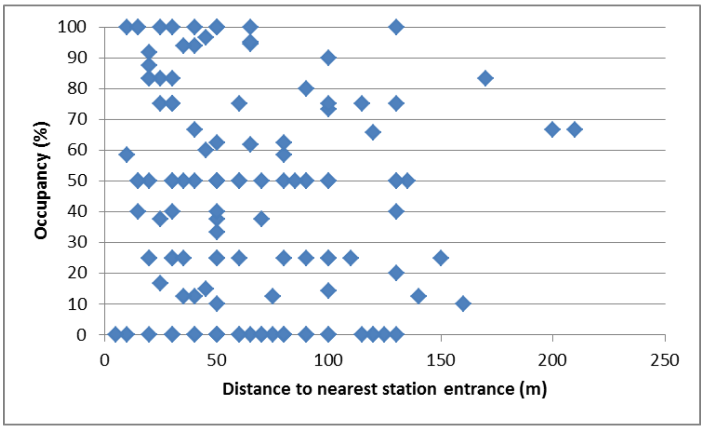


Table 1: Bicycle parking distance characteristics for different bicycle parking subgroups
Note: The *sample bicycles* column shows the total number of bicycles encountered during the five interchange surveys minus the outliers. The bottom row in the column shows the total number of NSW lockers observed leased on May 26th 2011.

Subgroup	Mean, m [Std. dev.]	Threshold distance, m [percentile bicycles]	Sample bicycles	Sample stations
Bicycles parked in the Open Air				
Bicycles parked at all stations	16.59[15.31]	23.2[94]	533	13
Bicycles parked at stations with hourly services <15 in the AM peak	10[14.35]	13.3[95]	34	5
Bicycles parked at stations with hourly services >30 in the AM peak	19.11[15.61]	26.2[93]	304	3
Bicycles parked at secure bicycle lockers	70.27[51.22]	-	506	83
Statistical Difference using t-test [p-value]				
Bicycles parked at stations with hourly services <15 in the AM peak vs bicycles parked at all other stations	-7.03[0.01]			
Bicycles parked at stations with hourly services >30 in the AM peak vs bicycles parked at all other stations	5.89[0.00]			
Open air bicycles parked vs bicycles parked at secure bicycle lockers*	-53.68[0.00]			

Two group mean t-tests were performed to verify the statistical significance of differences in parking distance amongst bicycle subgroups. The two group mean t-tests make evident to a 99% significance level that interchange service frequency and class of bicycle parking device are factors that indicate where bicycle parkers choose to distance, thus site, their bicycles. These two group t-tests are tabulated as part of Table 1.

Figure 6: Parking distance against occupancy of secure bicycle lockers



A plot of bicycle parking distance against occupancy of secure bicycle locker assemblages was formed. The occupancy of bicycle locker assemblages is found to only slightly decrease with parking distance. This provides further evidence to the cumulative plots that parking distance is not a very critical parameter for secure bicycle parking, in comparison to open-air bicycle parking. It can be interpreted the slight decreasing trend in occupancy with greater parking distance is caused by increasingly undesirable walking access distances to station entrances. Figure 6 shows this plot of parking distance against occupancy values of locker assemblages.

3.3 Predictive analysis

Ordinary Least Squares (OLS) Regression was used to determine the influence of streetscape amenity features upon where cyclists were observed to site their bicycles in the open-air. Interchange-specific and zonal characteristics of the zones of the surveyed interchanges were also included as predictors in the regression. Census data (Australian Bureau of Statistics, 2011) was used to include the zonal characteristics. 25 predictors were used in the full model, described in Table 3.

The dependent variable in the regression analysis was the count of bicycles found parked at each location, which is a value averaged over the five survey days. An average value was used to better reflect repeated behaviour. A total of 62 bicycle parking locations were observed, with an average and standard deviation of 1.7 and 2.5 bicycles parked at each location.

Table 2: Model summaries of the OLS regression and neural network models

OLS Reduced Model	Statistic	Value
	Sum of Squares Error	301.97
	Adjusted R Squared value	0.1205
Neural network		
Training	Sum of Squares Error for rescaled values of the dependent variable	3.571
	Relative Error for rescaled values of the dependent variable	0.121
	Stopping Rule Used	Maximum number of epochs (100) exceeded
Hidden Layer(s)	Number of Hidden Layers	1
	Number of Units in Hidden Layer 1*	3

* Excluding the bias unit

Table 3: Predictors used in the OLS regression and neural networks models

Predictor	Definition	Mean	Std. Dev.
Dummy location features			
lighting	1, if present at the location; 0, otherwise	0.968	0.177
shelter	1, if present at the location; 0, otherwise	0.397	0.493
cctv	1, if present at the location; 0, otherwise	0.103	0.272
ashop	1, if present at the location; 0, otherwise	0.508	0.504
ticketwindow	1, if present at the location; 0, otherwise	0.016	0.126
taxirank	1, if present at the location; 0, otherwise	0.286	0.455
busstop	1, if present at the location; 0, otherwise	0.365	0.485
footpath	1, if present at the location; 0, otherwise	0.952	0.215
housesapartments	1, if present at the location; 0, otherwise	0.016	0.126
street	1, if present at the location; 0, otherwise	0.762	0.429
offices	1, if present at the location; 0, otherwise	0.048	0.215
carpark	1, if present at the location; 0, otherwise	0.365	0.458
Continuous location characteristic			
distance	Parking distance to nearest station entrance (m)	22.46	26.087
Continuous interchange characteristics			
servicefrequency	Hourly train service frequency in the 7-9am peak	36.968	27.034
distancetocentral	Distance of interchange to Central Station (km), a station in the Central Business District	21.613	6.682
Land use variable			
pdensity	Population density per square km (thousands)	3.429	1.333
Demographic variables			
motor	Average motor vehicles per household member	0.453	0.05
income	Median personal weekly income (AUD$, thousands)	0.493	0.086
edensity	Employed persons per square km (thousands)	1.538	0.624
age2539	Percentage of residents aged 25-39	29.333	7.485
age4059	Percentage of residents aged 40-59	21.552	2.839
age2559	Percentage of residents aged 25-59	50.886	5.002
Bikeway supply variables			
offroad	Length of offroad cycle paths within 1km radius of the interchange (km)	1.89	1.64
onroad	Length of onroad cycle paths within 1km radius of the interchange (km)	4.745	2.677
totalbikeway	Total length of cycle paths within 1km radius of the interchange (km)	6.636	3.901

Table 4: Parameter estimation for the OLS regression and neural network models

		Neural Network				
		Hidden layer 1			Output Layer	Independent variable importance
Predictor	OLS reduced model [p-value]	H(1:1)	H(1:2)	H(1:3)	No. of Bicycles	Normalised importance (%)
lighting		0.431	-0.291	0.278		84.6
shelter	0.937[0.129]	-0.478	-0.291	-0.079		14
cctv	2.225[0.048]	0.022	-0.326	-0.144		23.2
ashop	1.038[0.083]	0.518	-0.025	0.041		19.9
ticketwindow		0.154	-0.406	0.413		74
taxirank		-0.103	-0.124	-0.842		7.5
busstop	1.172[0.065]	-0.953	-1.271	-0.077		31.8
footpath		0.317	0.658	0.124		36.9
housesapartments		-0.272	-0.515	0.02		40
street		0.223	0.253	-0.685		14.5
offices		0.904	0.511	-0.037		42.6
carpark		-0.606	-0.386	0.81		16.3
distance		0.923	2.797	0.307		72.4
service frequency		0.339	-1.106	0.807		75.5
distance to central		0.935	-0.708	0.173		92.5
pdensity		0.26	1.454	0.681		70.5
motor		-1.332	-1.581	0.047		64.3
income		-1.112	-1.361	-0.712		58.8
edensity		-0.533	0.757	1.043		100
age2539		-0.241	-0.461	0.231		24.6
age4059		0.028	0.185	-0.134		14.1
age2559		0.213	-1.236	0.446		61.3
offroad		-0.772	-1.344	-0.712		44.1
onroad		0.164	0.222	-0.547		17.5
totalbikeway		-0.487	-0.872	-0.591		34.8
constant	0.142[0.795]					
(Bias)		0.889	0.618	-0.407		
(Bias)					-0.139	
H(1:1)					1.945	
H(1:2)					-2.259	
H(1:3)					0.388	

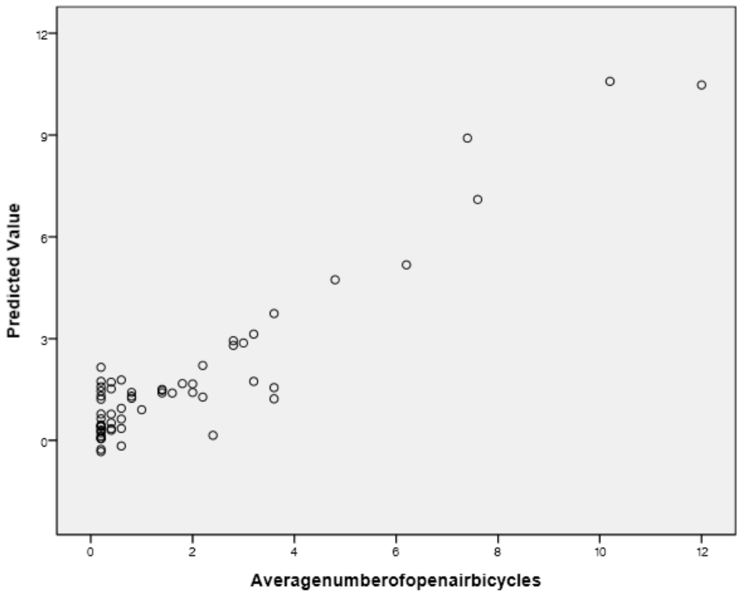
The agenda was to select a subset of the full set of predictors, which would meet multiple criteria. Ensuring the correlation between predictors as stipulated in a correlation matrix was less than 0.5, the constant value was minimised, all predictors were statistically significant and the adjusted r-squared value was maximised, a reduced model comprising of the independent variables ‘shelter’, ‘cctv’, ‘ashop’ and ‘busstop’ was selected. The adjusted r-squared value was 0.12 which is relatively small. The results of this reduced OLS model are shown in Tables 2 and 4.

Despite this low adjusted r-squared value, there is still some merit to the reduced OLS model. The remaining predictors in the reduced model were four dummy predictors representing the presence of bus stops, shops, CCTV cameras and shelter at bicycle parking locations. This suggests these location amenity features provide surveillance to assure cyclists their bicycles are left in a secure environment whereas shelter provides protection against the elements.

The low predictive ability of the reduced OLS model prompted a further predictive analysis. A neural networks prediction was performed to find a better fit between the available set of predictors against the dependent variable.

Under a Multilayer Perceptron procedure, ten trials of neural network prediction were performed. The results of a select trial characteristic of the lowest sum of squares error are shown in Table 4. It is evident there is a strong correlation between observed and predicted values of the dependent variable as shown visually in Figure 7.

Figure 7: Observed against neural network predicted values for the dependent variable



A different subset of predictors was indicated important by the neural network prediction, according to normalised importance values of predictors. The continuous predictors representing bicycle parking distance, service frequency of train stations, distance of the interchange to Central Station (Central Business District), population density and employment density are indicated important predictors to the number of bicycles found at locations. The normalised importance values are displayed in the rightmost column of Table 4. The importance of the variable representing distance of the interchange to Central Station coincides with findings indicating the location of interchanges in the urban fabric influencing the number of cycle-transit users (Keijer & Rietveld, 2009; Martens, 2004). The importance of population density agrees with previous mention of a relationship between bicycle use and population density (Hegger, 2007). Employment density being important in the model coincides with the recognition of commuting as significant in bicycle-transit trips (Chen et al. 2012; Lehman et al., 2009; Martens, 2004; Rietveld, 2000). The importance of train service frequency is in-line with the idea that larger passenger volumes provide greater pedestrian surveillance for encouraging bicycle parking at a train station.

4. Discussion

The study adopted a methodology to find useful information for siting of bicycle parking spaces and selecting between bicycle parking devices. The information can be used for suitable siting of bicycle parking and selection of parking devices so that bicycle parking patronage can be improved. Key findings include:

The results of the intra-day study provide support that open-air bicycle parking at train interchanges (and accordingly bicycle parking in general) in Australia is a long-stay activity. Thusly bicycle parking requires long-stay security against bicycle theft. At the studied station (Lidcombe station, Inner-West Sydney) it can be asserted this security is provided by the significant pedestrian traffic arising from its high train service frequency.

Siting of open-air bicycle parking is found to be dependent upon train service frequency of interchanges. Bicycle parking at less-busy train interchanges is found to be closer to station entrances than parking at busier interchanges. This may occur because bicycles at less-busy interchanges need to be parked closer in order to be seen by accessing and egressing passengers.

There is a significant difference in parking distance between bicycles in secure bicycle lockers and bicycles parked in the open-air. On an aggregate level, the results indicate secure bicycle parking facilities can be located at further distances to station entrances without significant deterioration in patronage. For a decision maker looking to implement bicycle parking spaces, this could mean secure bicycle lockers can be placed away from congested pedestrian approaches to maintain pedestrian safety whilst at the same time encouraging bicycle parking patronage.

The presence of shelter, CCTV cameras, shops and bus stops may be useful proxies to site open-air bicycle parking. This makes sense given shelter provides protection against the elements and the latter three indicate surveillance against bicycle theft. For example, shops attract pedestrian traffic and are occupied by shop staff.

Some demographic and urban form characteristics are indicated important predictors for bicycle parking levels. These were population density, employment density and location of interchanges in the urban fabric. This agrees with results of various literature discussing bicycle-transit demand (Chen et al., 2012; Hegger, 2007; Keijer & Rietveld, 1999; Lehman et al. 2009; Martens, 2004; Rietveld, 2000).

As a penultimate remark, the efficacy of interchange service frequency towards heterogeneously indicating suitable siting of bicycle parking spaces and selection between bicycle parking devices at interchanges is worthy of consideration. It is a continuous, objective and easily attainable characteristic for decision makers. This study adopted a methodology that was able to find bicycle parkers prefer to locate their bicycles differently according to different levels of interchange service frequency. It also indicated that service frequency may be a delineating factor to select between secure and non-secure parking devices at interchanges, given it is a proxy for bicycle surveillance against theft and vandalism. The implication is that less-busy train interchanges are in greater need for secure bicycle parking devices more than busier interchanges. This agrees with practice in the Netherlands where secure bicycle lockers are for the most part reserved for smaller stations (Hegger, 2007; Martens, 2007).

Of interest especially is the percentage of bicycles found parked *within* station walkways. 10% of all open-air bicycles are parked within station entrances and for bicycles parked at stations with hourly services <15 in the a.m. peak the percentage is 20%. This is evident with reference to Figures 4 and 5. This indicates the possible success of implementing bicycle parking facilities within station walkways and concourses, especially at less busy interchanges. Such is the widespread practice in Chicago with 83 CTA stations offering bicycle parking indoors (Pucher & Buehler, 2009).

References

Australian Bureau of Statistics 2011, Basic Community Profile Based on Usual Place of Residence, Cat. no. 2001, Australian Bureau of Statistics, Canberra, viewed 14 June 2013, http://www.abs.gov.au/websitedbs/censushome.nsf/home/communityprofiles?opendocument&navpos=230

Austroads 2008, Guide to traffic management: Part 11: Parking, report AGTM11/08, Austroads, Sydney, NSW

Bachand-Marleau, J, Larsen, J, El-Geneidy AM 2011, 'Much Anticipated Marriage of Cycling and Transit: How Will It Work?', Transportation Research Record: Journal of the Transportation Research Board, n 2247, pp. 109-117.

Chen, L, Pel, AJ, Chen, X, Sparing, D, Hansen, IA 2012, 'Determinants of Bicycle Transfer Demand at Metro Stations', Transportation Research Record: Journal of the Transportation Research Board, n 2276, pp. 131-137.

Hegger, R 2007, 'Public transport and cycling: Living apart or together?', Public Transport International, v 56, n 2, pp. 38-41.

Keijer, MJN, Rietveld, P 1999,'How do people get to the railway station? The Dutch experience', Transportation Planning and Technology, v 23, n 3, pp. 215-235.

Lehman, R, Zhong, J, Cheng, C 2009, ‘The provision and use of bicycle parking at Sydney region public transport interchanges’, Results of facilities audit and cyclist questionnaire. Prepared for the New South Wales Premier's Council for Active Living.

Martens, K 2004, 'The bicycle as a feedering mode: Experiences from three European countries', Transportation Research Part D: Transport and Environment, v 9, n 4, pp. 281-294.

Martens, K 2007, 'Promoting bike-and-ride: The Dutch experience', Transportation Research Part A: Policy and Practice, v 41, n 4, pp. 326-338.

Martin, S 2010, Parkiteer – Secure bicycle parking at PT nodes, The Faculty of Architecture, Building and Planning: The University of Melbourne, viewed on 20 October 2011, http://www.abp.unimelb.edu.au/files/miabp/11Martin.pdf

Martin, S, den Hollander, J 2009, 'Parkiteer - Secure Bicycle Parking at Public Transport Nodes in Melbourne', 32nd Australasian Transport Research Forum

Moskovitz, DA & Wheeler, N 2011, 'Bicycle Parking Analysis with Time Series Photography', Transportation Research Record, n 2247, pp. 64-71.

NSW Government 2013, NSW Government, viewed 14 June 2013, https://appln.transport.nsw.gov.au/bikelockers/faces/jsp/public/home.xhtml

NSW RAIL CORPORATION 2013, NSW RAIL CORPORATION, viewed 14 June 2013, http://www.cityrail.info/

Parker, AA 1992, 'Beating bicycle theft - a modern-day plague which discourages cycling', Australian Cyclist, v 16, n 4, pp. 23-25

Pucher, J, Buehler, R 2009, 'Integrating Bicycling and Public Transport in North America', Journal of Public Transportation, v 12, n 3, pp.79-104.

Rietveld, P 2000, 'The accessibility of railway stations: the role of the bicycle in The Netherlands', Transportation Research Part D: Transport and Environment, v 5, n 1, pp.71-75

Third Wave Cycling Group Inc., Via Architecture, Halcrow Consulting 2010, Cycle Support Services Study - Pilot Bicycle Enclosures study , viewed on 20 October 2011, http://www.translink.ca/~/media/Documents/cycling/regional_cycling_strategy/Cycle%20Support%20Services%20Pilot%20Bicycle%20Enclosures%20Study.ashx