The Calculation of Perceived Residential Density

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INTRODUCTION

In recent years, a number of studies (e.g. Newman and Kenworthy, 1989) have sought to demonstrate that a range of urban functions are affected by the residential density of the urban area. Newman and Kenworthy, for example, suggest that private vehicle usage and fuel consumption are related to residential density and state that "if cities around 10/ha were able to consolidate and move to densities around 30/ha then fuel consumption could be reduced by half" (Newman and Kenworthy, 1989, p.47). However, several authors (e.g. Brindle, 1994) have questioned the interpretations placed on Newman and Kenworthy's results.

Other questions have also been raised about the computational validity of some of the calculations of urban density used in these studies. In particular, questions have been raised as to what is a reasonable definition of the urban area over which the density should be calculated. If the urban area is defined very tightly to include only those built-up areas within the urban boundaries (however defined), then the density will be higher than if a liberal definition is adopted for the urban area which includes the fringe areas and undeveloped parts of the city. Indeed, Newman and Kenworthy themselves (1989, p. 28) question what should be the definition of "urban land', and use Paris as an example to show that urban densities can vary by a factor of about two, depending on what definition is used for the urban area of Paris. However, while they raised the question, they did not provide a definitive answer as to how to define the urban area of any city. While they devote several tables in their book (Tables 2.3, 2.4 and 2.5) to providing the definitions of metropolitan areas, inner areas and CBD, such definitions are relatively arbitrary and are not adhered to even in Newman and Kenworthy's own calculations.

This paper seeks to define and illustrate a computational technique which takes most of the arbitrariness out of the definition of an urban area, such that the calculation of urban densities is relatively insensitive to the precise definitions used for the urban area of a city. Indeed, the geographic definition of the urban area can be relatively generous, and the computational technique will automatically adjust the density calculations such that they only apply to the populated urbanised area of the city. The adoption of such a technique is imperative when urban densities are being used to compare different cities of Australia, for urban planning or socio-political reasons, or where Australian cities are being compared with other cities worldwide. The adoption of the techniques described in this paper will ensure that such comparisons are made on a firmer theoretical and computational foundation.

THE CONCEPT OF PERCEIVED RESIDENTIAL DENSITY

If one conducted a survey of residents to find out the density they experience, one would obtain a higher value of residential density than by simply dividing the total residents by the total land area of the "urban area". There are more people who live in high density situations (per unit of land) than there are people living in low density areas. A "population-weighted" average of residential density will therefore give a higher residential density than an "area-weighted" density.

More importantly, a "population-weighted" average of residential density will give a value of residential density which is not affected by the addition of spurious empty regions to the outskirts of the urban area, because their lack of population means that they won't be counted in a "population-weighted" calculation, thereby removing a major source of potential bias in the calculation of residential density.

CONSIDER THE CITY OF MELBOURNE

To give an example of the calculation of perceived residential densities, consider the data for the Melbourne Statistical Division (SD) at the SSD (Statistical Sub-Division) level, as shown in Table 1. There are 18 SSDs in the Melbourne SD, ranging from the Central City area (20525) out to the newly developing fringe areas (such as 20580).

Table 1 Residential Densities for the Melbourne Statistical Division (SD)

SSD	Population	Area (ha)	Density	% Population	% Area
20525	88,666	2,875	30.84	3%	0%
20565	166,724	6,482	25.72	6%	1%
20505	203,787	8,167	24.95	7%	1%
20545	135,655	5,855	23.17	5%	1%
20510	119,401	5,426	22.01	4%	1%
20530	178,036	8,618	20.66	6%	1%
20570	171,514	9,458	18.13	6%	1%
20550	263,115	16,897	15.57	9%	2%
20555	294,206	21,125	13.93	10%	3%
20585	108,203	8,336	12.98	4%	1%
20515	233,114	21,689	10.75	8%	3%
20575	144,875	13,696	10.58	5%	2%
20535	140,540	48,755	2.88	5%	6%
20540	197,437	94,885	2.08	7%	12%
20590	91,816	71,077	1.29	3%	9%
20520	105,424	111,900	0.94	4%	14%
20580	166,606	177,182	0.94	6%	23%
20560	139,536	149,059	0.94	5%	19%
Total SD	2,948,655	781,482	3.77	100%	100%

It can be seen that the residential density (in persons/ha) varies considerably across the SSDs, from over 30 in the central area to less than 1 in the fringe areas. Across the entire SD, the average residential density is 3.77 persons/ha. Importantly, this is the figure which would be calculated on the basis of the statistical definition of the Melbourne metropolitan area (i.e. the SD) as specified by the Australian Bureau of Statistics (ABS). However, clearly a density of 3.77 is not representative of most of Melbourne, as shown in Table 1. A more realistic measure, which accounts for the residential densities in which people actually live, is given by the "population-weighted" perceived density. Based on Table 1, and weighting the SSD densities by the SSD population and not the SSD area, this perceived density is 13.44 persons per hectare. However, even this figure is somewhat misleading because the SSDs are, in themselves, highly aggregated areas. If one worked with a finer level of aggregation (going down to the Census Collectors District (CCD) at the finest level), then different densities will be obtained, as shown in Table 2 and Figure 1.

Table 2 Perceived Residential Densities for Different Zone Sizes in Melbourne

Zone	Average Area (hectare)	Average Population	Average Density (person/ha)	Average Space (ha/person)
SD	781,482	2,948,655	3.77	0.27
SSD	43,416	163,814	13.44	0.07
SLA	13,474	50,839	15.24	0.07
CDPC	3,077	11,609	17.72	0.06
CSDN	1,681	6,341	19.64	0.05
CCD	157	592	28.21	0.04

Note: SLA = Statistical Local Area
CDPC = Census-Derived PostCode
CSDN = Census Sub-Division Number

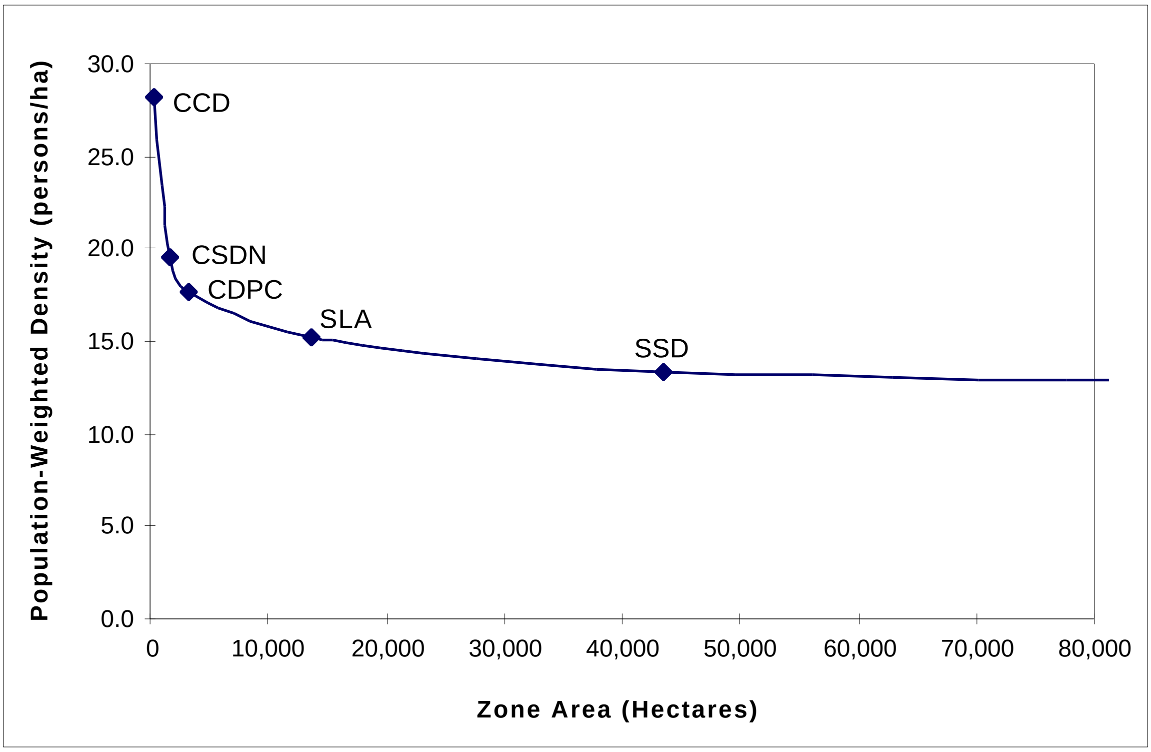

Figure 1 Population-Weighted Perceived Density as a Function of Zone Area

It can be seen that when considered at the level of the CCD, the average perceived residential density for all Melbourne residents is nearly 30 persons/ha. That is, if you surveyed all Melbourne residents and asked them to state the local (to the level of a CCD) residential density at which they lived, the average response would be nearly 30 persons/ha. The reason for this high average density can be seen from consideration of Figure 2, which shows a Lorenz Curve plotting the cumulative population living in a cumulative area of Melbourne. It can be seen that nearly 90% of the population of the Melbourne Metropolitan Area lives in only 20% of the land area of the Melbourne Metropolitan Area.

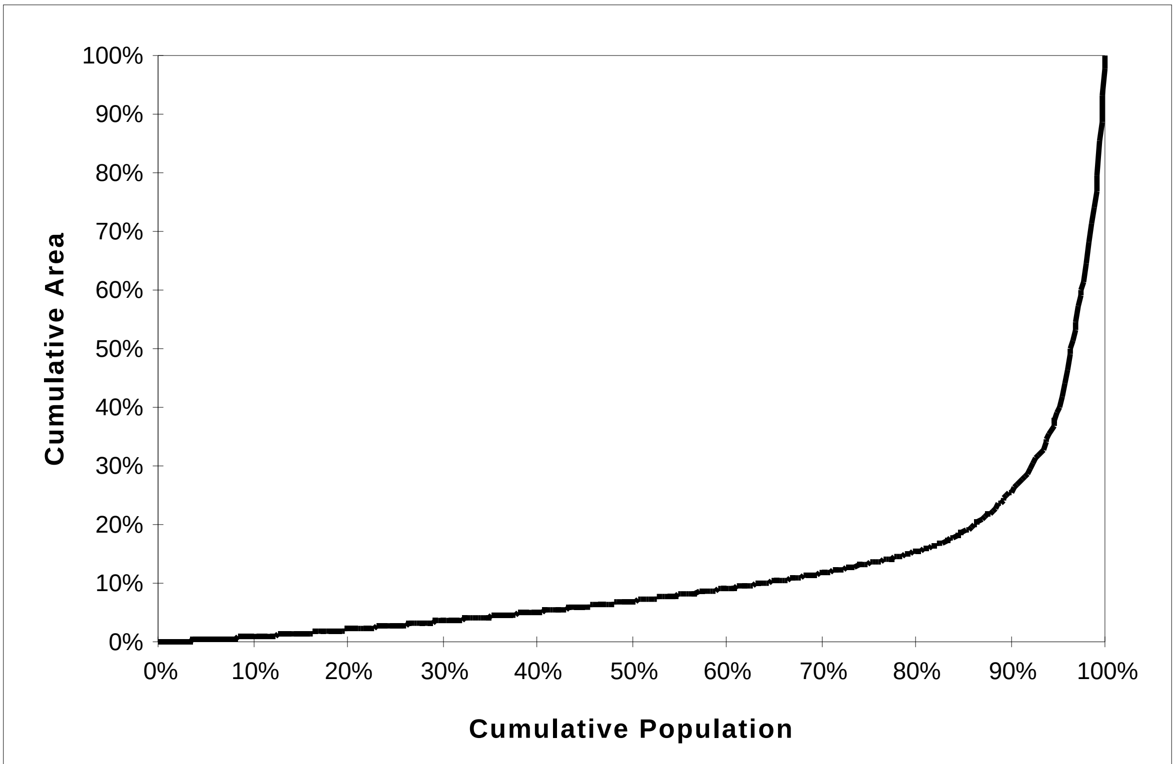

Figure 2 A Lorenz Curve for Residential Density in Melbourne

The same trends can be shown to exist in other Australian capital cities, as demonstrated in Table 3 where residential densities are calculated for different ABS (Australian Bureau of Statistics) zone definitions. These results are also shown graphically in Figure 3 for all Australian capital cities. It can be seen from Figure 3 that Sydney and Melbourne have relatively similar densities, especially for the larger zone sizes, while the other cities fall into two main groups (Brisbane-Perth-Adelaide-Canberra, and Hobart-Darwin). However, examination of Table 3 shows that if residential density was calculated on the level of the Statistical Division (SD) totals, the most dense Australian capital city would appear to be Adelaide (at 5.18 persons per hectare). Clearly, in the light of the evidence in Figure 3, such a calculation is misleading and should not be used in comparing Australian cities.

Table 3 Perceived Residential Densities for Different Zone Sizes in Capital Cities

Zone	Average Area (hectare)	Average Population	Average Density (person/ha)	Average Space (ha/person)
Sydney				
SD	1,215,539	3,433,183	2.82	0.35
SSD	86,824	245,227	14.12	0.07
SLA	27,012	76,293	17.52	0.06
CDPC	4,786	13,516	23.03	0.04
CSDN	2,289	6,466	26.21	0.04
CCD	203	573	37.15	0.03
Melbourne				
SD	781,482	2,948,655	3.77	0.27
SSD	43,416	163,814	13.44	0.07
SLA	13,474	50,839	15.24	0.07
CDPC	3,077	11,609	17.72	0.06
CSDN	1,681	6,341	19.64	0.05
CCD	157	592	28.21	0.04
Brisbane				
SD	461,975	1,292,369	2.80	0.36
SSD	51,331	143,597	5.01	0.20
SLA	2,081	5,821	12.70	0.08
CDPC	7,275	20,352	10.87	0.09
CSDN	1,540	4,308	13.38	0.07
CCD	198	553	18.83	0.05
Perth				
SD	545,634	1,106,700	2.03	0.49
SSD	109,127	221,340	3.09	0.32
SLA	16,534	33,536	8.40	0.12
CDPC	5,402	10,957	11.20	0.09
CSDN	3,267	6,627	12.50	0.08
CCD	268	544	18.92	0.05
Adelaide				
SD	191,834	993,069	5.18	0.19
SSD	47,959	248,267	6.29	0.16
SLA	5,995	31,033	11.41	0.09
CDPC	1,547	8,009	15.08	0.07
CSDN	1,096	5,675	15.61	0.06
CCD	104	539	19.96	0.05
Canberra				
SD	80,738	267,773	3.32	0.30
SSD	13,456	44,629	6.88	0.15
SLA	816	2,705	14.75	0.07
CDPC	3,510	11,642	10.93	0.09
CSDN	832	2,761	14.76	0.07
CCD	189	630	18.01	0.06
Hobart				
SD	93,681	176,065	1.88	0.53
SSD	93,681	176,065	1.88	0.53
SLA	11,710	22,008	2.91	0.34
CDPC	3,230	6,071	8.24	0.12
CSDN	3,022	5,680	8.42	0.12
CCD	277	521	15.01	0.07
Darwin				
SD	20,828	78,401	3.76	0.27
SSD	10,414	39,201	5.64	0.18
SLA	595	2,240	15.42	0.06
CDPC	2,604	9,800	11.80	0.08
CSDN	595	2,240	15.42	0.06
CCD	165	622	18.73	0.05

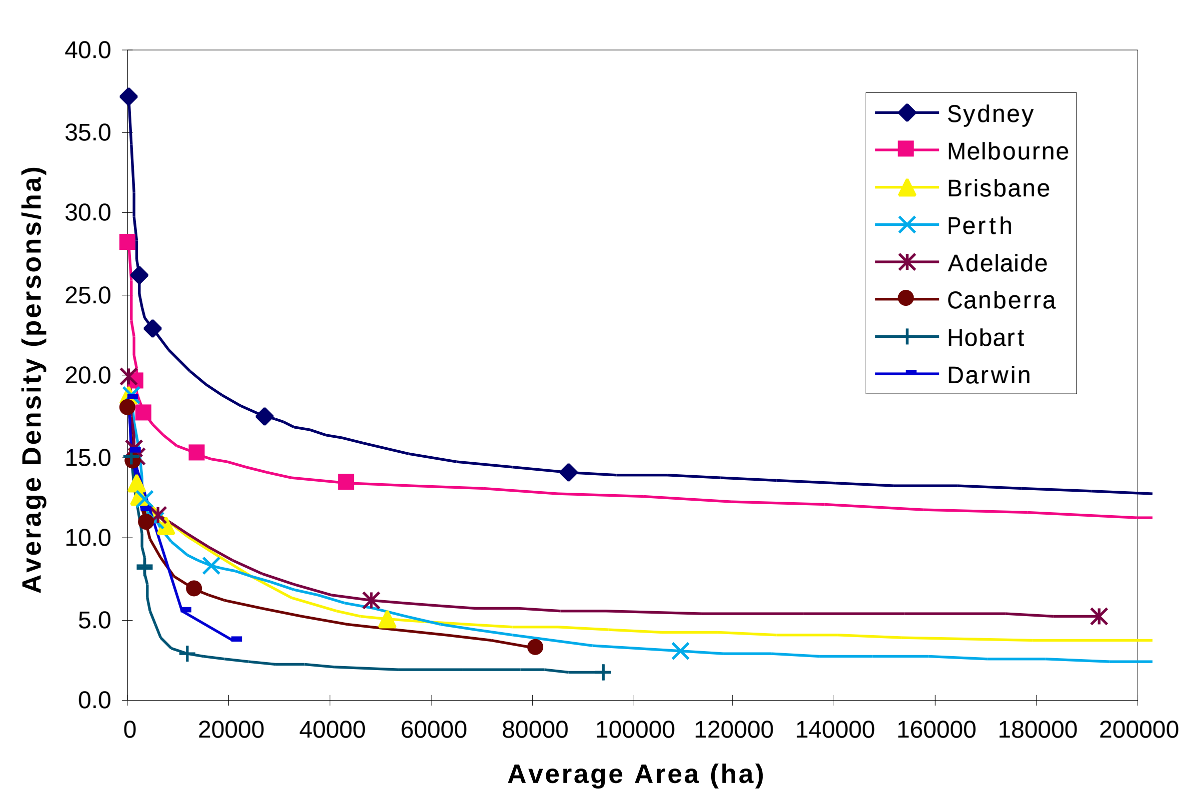

Figure 3 Population-Weighted Perceived Densities as a Function of Zone Area

APPLICATION TO OVERSEAS CITIES

While the above analysis has highlighted the problem of using "area-weighted" residential densities when comparing Australian capital cities, the question remains as to the extent to which this same problem exists in other non-Australian cities with which Australian cities are regularly compared. To illustrate the application of the method to overseas cities, the above calculations are repeated for the city of Zurich, Switzerland. Population and area data has been obtained from the Swiss Federal Office for Statistics, and "population-weighted" average densities have been calculated for three levels of zonal aggregation. While the zonal areas have different names in Switzerland, they have been titled as SSDs, SLAs and CSDNs in the following tables, based on their approximate size similarities with Australian cities. The populations, areas and "population-weighted" densities for Zurich are shown in Table 4.

Table 4 Perceived Residential Densities for Different Zone Sizes in Zurich

Zone	Average Area (hectare)	Average Population	Average Density (persons/ha)	Average Space (ha/person)
"SSD"	77,113	927,996	12.03	0.083
"SLA"	7,711	92,800	22.35	0.045
"CSDN"	907	10,918	24.96	0.040

To enable an easy comparison with Australian cities, the data from Table 4 for Zurich are plotted with the data from Table 3 for Sydney, as shown in Figure 4. It can be seen that, over the range of zone sizes applicable to both cities, Zurich and Sydney have very similar perceived densities. The main difference is that, being a much smaller city, the whole of Zurich (about 80,000 ha) could fit within an average Statistical Local Area (SLA) in Sydney. Sydney, in essence, is a European city (Zurich) surrounded by a large contiguous area of lower density residential development. However, to the extent that is possible, Sydney has developed its inner urban residential population as much as a typical European city. It is therefore somewhat misleading to say that Australian cities are much lower density than European cities; they are not lower density for comparable areas, they are just bigger!

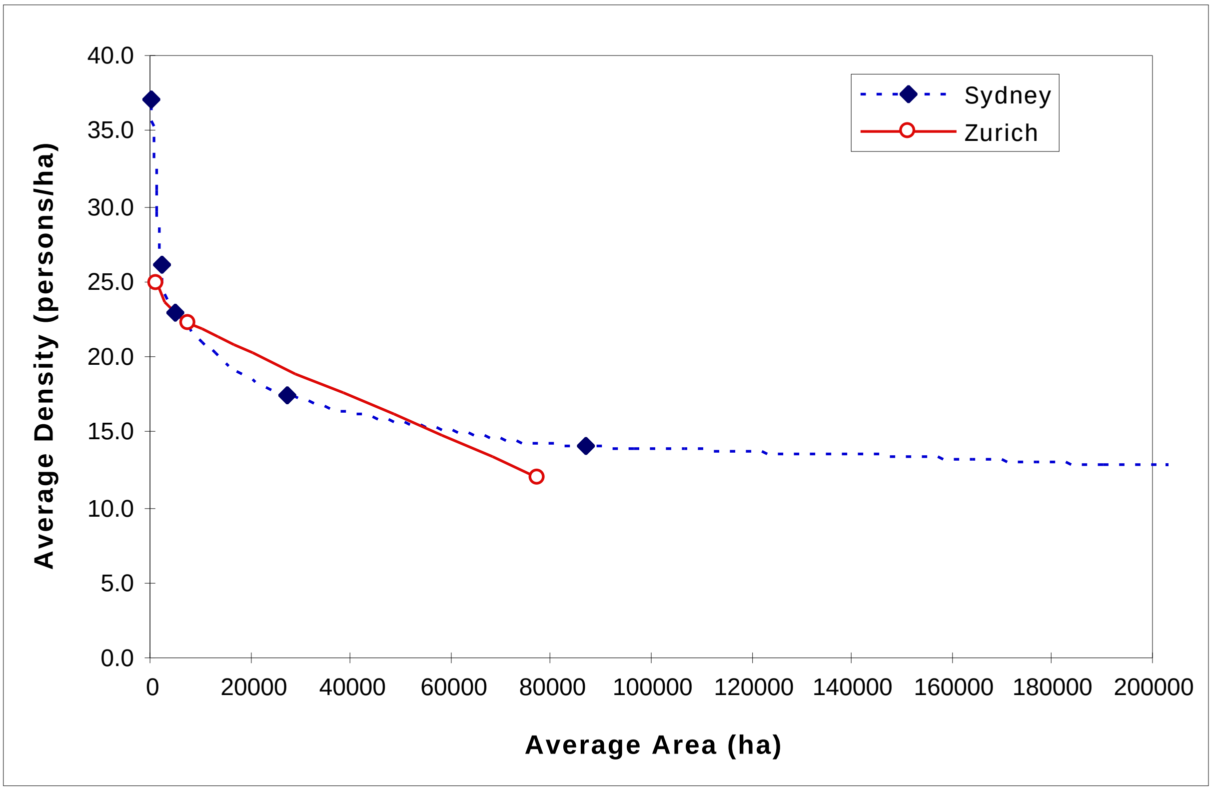

Figure 4 Population-Weighted Perceived Densities for Zurich and Sydney

Ongoing research is being conducted by applying this method of calculating residential densities to other world cities, thus enabling a more valid comparison of city densities on a global scale.

CORRECTING FOR THE SIZE OF THE ZONE

Figure 3 shows that the average perceived density varies with the size of the zone used in the calculation of that density. There is, therefore, a need to standardise the zone size used in the calculations to enable uni-dimensional comparisons between cities. Unfortunately, there is no natural standardisation apparent in the ABS (Australian Bureau of Statistics) zone definitions used in Tables 2 and 3. Statistical Local Areas, for example, vary in size from 595 hectares in Darwin up to 27,012 hectares in Sydney. Even the most disaggregate zones (CCDs), which nominally contain the same number of households, vary in physical size from 104 ha in Adelaide up to 277 ha in Hobart. Therefore, an arbitrary zone size needs to be chosen for standardisation. In line with the basic concept of perceived density, the zone size chosen should reflect the "perceived neighbourhood" of the resident, within which they are calculating their local residential density. Further research needs to be undertaken as to what physical size is a reasonable representation of this "local area", but for the remainder of this paper, a size of 10,000 ha is arbitrarily adopted for standardisation purposes. The choice of this size zone ensures that all capital cities are larger than this zone size, thus enabling standardisation within the range of results obtainable for each city. While it is realised that 10,000 ha is a large "local area" and that the absolute values of the densities would change if a different zone size had been used, the relative values of the densities remain fairly constant (as will be shown later in Table 10). The task therefore is to calculate the perceived density in each city using one of the ABS zone definitions and then adjust the perceived density to what it would have been if a zone size of 10,000 ha had been used.

The standardisation process requires that the discrete results shown in Figure 3 be converted to a continuous equivalent result from which a value for a zone size of 10,000 ha can be estimated. After exploring various transformations, it was found that a logarithmic transformation of the zone area produced a reasonably linear inverse relationship with average perceived residential density, as shown in Figure 5. The fits for all cities are not perfect, especially for the smaller cities, but seem to capture most of the variations acceptably.

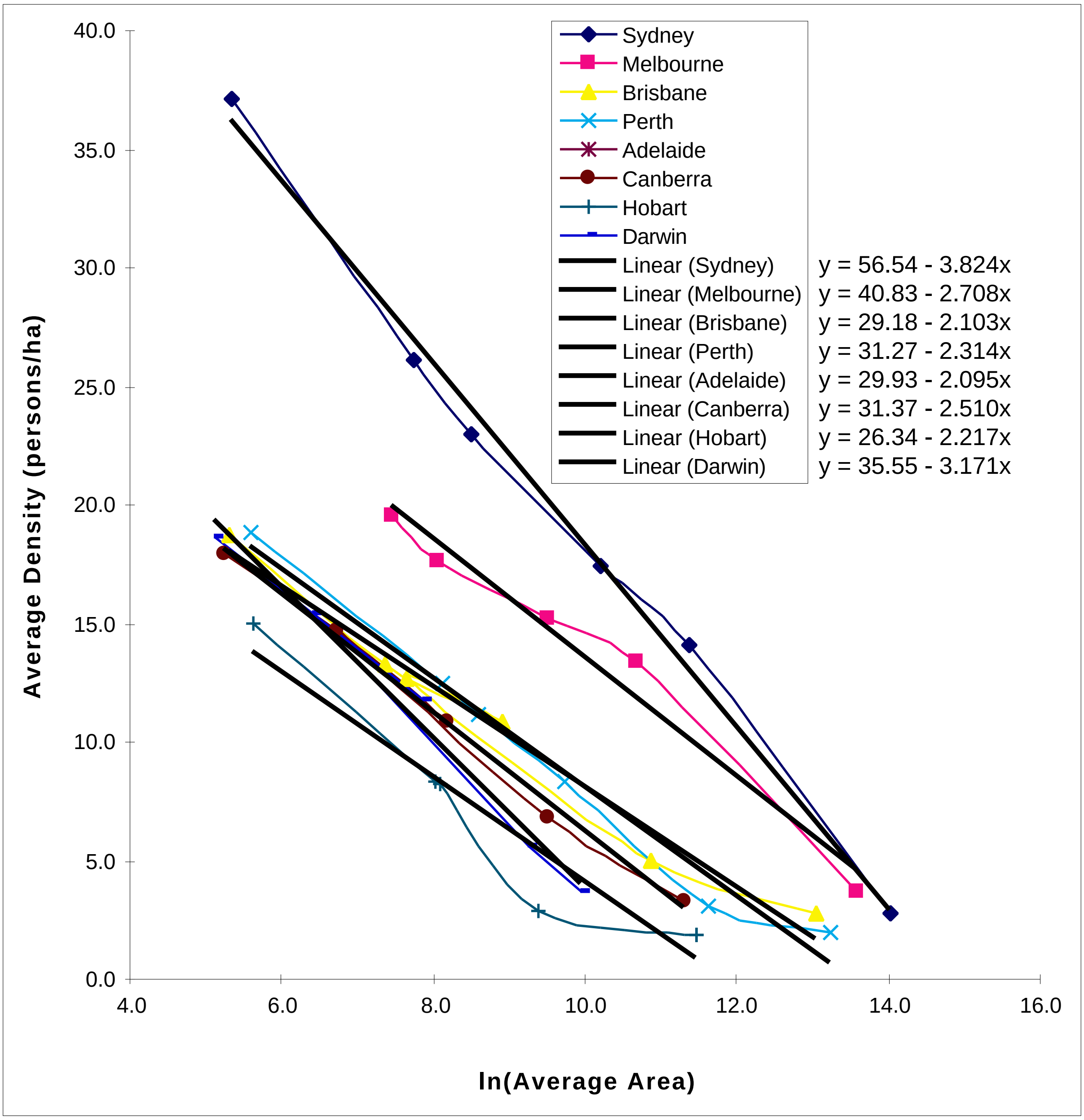

Figure 5 Logarithmic Transformations of Zone Area Relationships

From the log-linear relationships, the equations are used to estimate perceived densities at various assumed zonal areas, as shown in Table 5. Some comment needs to be made on some strange results obtained for the smaller cities at large assumed zone sizes. For example, at a zone size of 80,000 ha, Darwin is estimated to have a negative perceived density! This does not mean that a "black hole" would be created in Darwin; rather it simply says that the equation would not hold at this zone size since the entire area of Darwin is only 20,828 ha.

Table 5 Perceived Residential Densities for Assumed Zone Sizes in Capital Cities

s	Average Zonal Area (10,000 ha)							
	1	2	3	4	5	6	7	8
Sydney	1.00	0.88	0.80	0.75	0.71	0.68	0.65	0.63
Melbourne	1.00	0.89	0.82	0.78	0.74	0.71	0.69	0.67
Brisbane	1.00	0.85	0.76	0.70	0.66	0.62	0.58	0.55
Perth	1.00	0.84	0.74	0.68	0.63	0.58	0.55	0.52
Adelaide	1.00	0.86	0.78	0.73	0.68	0.65	0.62	0.59
Canberra	1.00	0.79	0.67	0.58	0.51	0.46	0.41	0.37
Hobart	1.00	0.74	0.59	0.48	0.40	0.33	0.27	0.22
Darwin	1.00	0.65	0.45	0.31	0.20	0.10	0.03	-0.04
Average	1.00	0.84	0.74	0.67	0.62	0.57	0.54	0.51

The perceived densities calculated in Table 5 are now divided by the perceived density at a zone size of 10,000 ha to calculate a zone size correction factor, as shown in Table 6. The zone size correction factors are used to adjust the perceived densities calculated at any given zone size to the density which would have been obtained at a standard zone size of 10,000 ha, by dividing the calculated density by the zone size correction factor.

Table 6 Zone Size Correction Factors

s	Average Zonal Area (1000 ha)							
	1	2	3	4	5	6	7	8
Sydney	1.00	0.88	0.80	0.75	0.71	0.68	0.65	0.63
Melbourne	1.00	0.89	0.82	0.78	0.74	0.71	0.69	0.67
Brisbane	1.00	0.85	0.76	0.70	0.66	0.62	0.58	0.55
Perth	1.00	0.84	0.74	0.68	0.63	0.58	0.55	0.52
Adelaide	1.00	0.86	0.78	0.73	0.68	0.65	0.62	0.59
Canberra	1.00	0.79	0.67	0.58	0.51	0.46	0.41	0.37
Hobart	1.00	0.74	0.59	0.48	0.40	0.33	0.27	0.22
Darwin	1.00	0.65	0.45	0.31	0.20	0.10	0.03	-0.04
Average	1.00	0.84	0.74	0.67	0.62	0.57	0.54	0.51

However, since the size of the zone used in the calculation of the perceived density is unlikely to be an even multiple of 10000ha, as shown in Table 6, it is necessary to obtain continuous approximations to these zone size correction factors as a function of the average area of the zone used in the calculations. The values from Table 6 are therefore plotted in Figure 6, together with the 3rd-order polynomials of best fit. The polynomials are a very good fit, covering the data points from Table 6 almost perfectly. The coefficients of the equations of best fit are shown in Table 7. It can be seen that there is a systematic relationship between the coefficients for each power in the polynomial and the constant term and the size (or density) of the cities, with the larger cities generally having smaller values of the coefficients. This ordering, however, is not perfect with Melbourne (the second largest and second densest city) having the lowest value of the coefficients and Adelaide also being misplaced in the ordering of the cities. The search for a relationship between the values of the coefficients and a measure of city structure is continuing in an effort to find a single zone size correction factor curve whose coefficients can be expressed as a function of an easily measured city parameter.

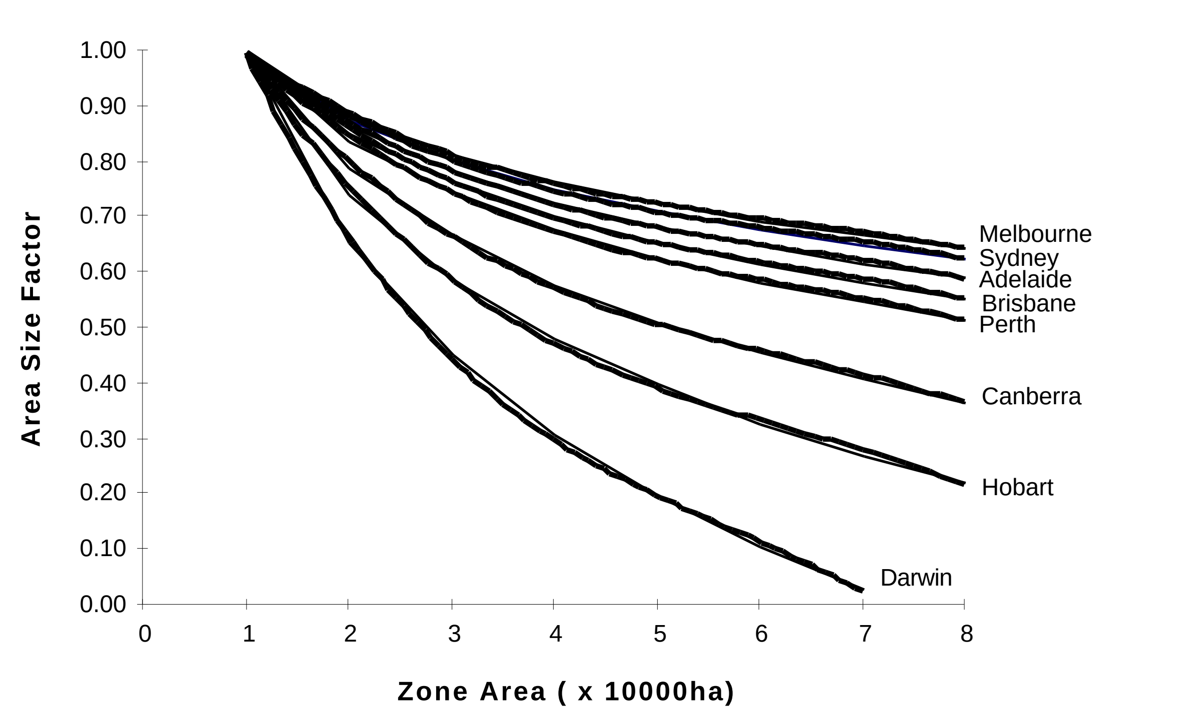

Figure 6 Zone Size Correction Factors and the 3rd-order Polynomial Best-Fits

Table 7 Coefficients on the Zone Size Correction Factor Polynomials

	x^3	x^2	x	a
Sydney	-0.0013	0.0238	-0.1761	1.1499
Melbourne	-0.0011	0.0213	-0.1575	1.1341
Brisbane	-0.0015	0.0285	-0.2101	1.1790
Perth	-0.0016	0.0309	-0.2283	1.1944
Adelaide	-0.0014	0.0262	-0.1933	1.1646
Canberra	-0.0021	0.0404	-0.2985	1.2542
Hobart	-0.0026	0.0498	-0.3678	1.3132
Darwin	-0.0047	0.0795	-0.5317	1.4510

AN APPLICATION OF THE METHOD

The techniques outlined above may be applied to calculate comparable perceived residential densities for Australian capital cities. The densities have been calculated on the basis of Statistical Local Area (SLA) zones and then adjusted to a common zone size of 10,000 ha, as shown in Table 8.

Table 8 Calculation of Zone-Size-Adjusted Perceived Densities

	SLA Area (ha)	SLA density (person/ha)	Zone Size Correction Factor	Adjusted Perceived Density
Sydney	27012	17.52	0.822	21.31
Melbourne	13474	15.24	0.958	15.91
Brisbane	2081	12.70	1.136	11.17
Perth	16534	8.40	0.894	9.39
Adelaide	5995	11.41	1.058	10.78
Canberra	816	14.75	1.230	11.99
Hobart	11710	2.91	0.947	3.07
Darwin	595	15.42	1.420	10.86

It can be seen that the ordering of zone-size-adjusted perceived residential densities is much more in accord with expectations than the densities calculated on the total size of the Statistical Division. Clearly, Sydney is the densest of the capital cities, and not Adelaide as would be implied from the SD calculations. Some variations in the perceived densities would occur if a zone size of other than 10,000 were used, as shown in Table 9.

Table 9 Variations in Perceived Density with Zone Size

	Average Zonal Area (ha)							
	2500	5000	7500	10000	12500	15000	17500	20000
Sydney	26.62	23.97	22.42	21.32	20.47	19.77	19.18	18.67
Melbourne	18.99	17.27	16.26	15.54	14.98	14.53	14.14	13.81
Brisbane	12.74	11.28	10.43	9.82	9.35	8.97	8.64	8.36
Perth	13.16	11.55	10.62	9.95	9.43	9.01	8.66	8.35
Adelaide	13.54	12.09	11.24	10.64	10.17	9.79	9.46	9.18
Canberra	11.73	9.99	8.98	8.25	7.69	7.24	6.85	6.51
Hobart	8.99	7.45	6.55	5.92	5.42	5.02	4.68	4.38
Darwin	10.74	8.54	7.26	6.34	5.64	5.06	4.57	4.15

However, if the relative densities are calculated (by reference to Sydney), it is clear that the relativities do not change significantly over a wide range of assumed local area zone sizes, at least for the largest of the cities as shown in Table 10. Thus Melbourne is about three-quarters the density of Sydney, while Brisbane, Perth and Adelaide are about half as dense as Sydney. Only the very smallest of the capital cities (Canberra, Hobart and Darwin) show any significant variation in relative density, becoming more dense (relative to Sydney) as the zone size decreases.

Table 10 Relative Perceived Density as a Function of Zone Size

	Average Zonal Area (ha)							
	2500	5000	7500	10000	12500	15000	17500	20000
Sydney	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Melbourne	0.71	0.72	0.73	0.73	0.73	0.73	0.74	0.74
Brisbane	0.48	0.47	0.47	0.46	0.46	0.45	0.45	0.45
Perth	0.49	0.48	0.47	0.47	0.46	0.46	0.45	0.45
Adelaide	0.51	0.50	0.50	0.50	0.50	0.50	0.49	0.49
Canberra	0.44	0.42	0.40	0.39	0.38	0.37	0.36	0.35
Hobart	0.34	0.31	0.29	0.28	0.26	0.25	0.24	0.23
Darwin	0.40	0.36	0.32	0.30	0.28	0.26	0.24	0.22

CONCLUSION

This paper has demonstrated a method of calculating residential densities which takes account of the number of people living at various levels of residential density. Using readily available data on the size and population of standard Census zones, it is shown that calculating a population-weighted average, rather than an area-weighted average, gives a more behaviourally correct measure of perceived density. Importantly, it also provides a calculation technique which obviates the need to define an arbitrary size of an "urban area" before calculating the density, since the population-weighted average automatically discounts zones with large areas, but little population., on the outskirts of the city.

The paper has shown that the size of the perceived residential density is a function of the zone size used to calculate the density, but then proceeds to develop a technique whereby the effect of this zone size can be corrected. The relative perceived densities thus calculated are shown to be fairly stable across a wide range of "local areas" within which perceived density might be thought to apply.

The techniques developed in this paper should be useful in defining a calculation methodology which can be applied to cities in any part of the world. The data that is required is a table of areas and populations of zones (of various sizes) within the city being considered (such tables are readily available from Census Bureaus or City Planning Offices), from which a population-weighted average is calculated. For comparison with other cities, this average density then needs to a standardised to a common value of the size of a "local area". Further research needs to be undertaken as to what physical size is a reasonable representation of this "local area", but for Australian cities, at least, a nominal value of 10,000 ha seems to produce reasonably robust results.

The main advantage of this method is that the need to define an "urban area" before the calculation of the density is done away with, thereby removing one source of arbitrariness in the calculation and comparison of urban densities. Ongoing research is being conducted by applying this method of calculating residential densities to other world cities, thus enabling a more valid comparison of city densities on a global scale.

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