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Investigating the spatio-temporal changes in major activity centres in the Sydney metropolitan area

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Abstract

Every assessment of urban spatial structure requires determining the importance of activity centres. This paper gives an attempt to analyse the spatial and temporal changes experienced by major activity centres in the Sydney metropolitan area. The objectives of the research were first, to explore the role of main activity centres on the distribution of job opportunity across the metropolitan area, second to find out whether or not these key activity centres were influential in making the Sydney's urban structure more poly-centric rather than being a mono-centric. It also estimates how accessible these activity centres are for the workforce and what their corresponding labour catchment areas are. Eleven activity centres were chosen based on the preliminary analysis of Sydney's planning and development documents and exist evidences on living and working spots. A number of analysing techniques such as mapping of journeys to work in these centres, influence circles of centres, employment preference functions, and tabular data on the levels of employment were applied. The results of the analysis show that apart from the CBD, North Sydney, Parramatta and Inner City the remaining activity centres appear to exert slight impact on employment distribution across the metropolitan area. There does not seem to be evidence for a significant poly-centric structure in Sydney metropolitan area in regarding with employment recruitment, seeking and retention.

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1. Introduction

1.1. Literature review

Cities and urban spatial structure have had a long history of research by economists, planners, geographers and others. The focus has been on the theoretical foundations of urban spatial structure and empirical foundations primarily through development and testing of various mono-centric and polycentric urban models (Baumont and Gallo, 1999). The understanding of urban spatial

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structure from these studies has been influential in the modelling of future growth patterns for cities (Clarke et al., 1997; Foot, 1981; Landis and Zhang, 1998; Spiekermann and Wegener, 2003; Waddell, 1998).

In the above models a key variable is distance from the CBD or distance to the urban fringe, and there are also other variables relevant to urban expansion such as income, agricultural land value and transportation costs, and so on. The theoretical principles of polycentric centres in urban space are found in the assumptions associated with urban growth strategies. For example, in *A Plan for Growing Sydney*, released in December 2014 is largely structured around the notion of a hierarchy of centres across the metropolitan area, and future spatial growth trajectories are targeted at existing and new centres thereby making use of both agglomeration and location economies. It could also be argued that many anti-sprawl strategies, smart growth and densification strategies now common in urban planning and policy (El-Garouania et al., 2016). But the reactions to the concept of urban expansion inherent in these models, are reflected in growth in central city core areas and in higher density urban villages – small islands of higher density development and mixed services (Torrens, 2008). The polycentric centres and the urban villages represent some of the bumps in the monotonic density decay curve with distance from the CBD that is typical of the mono-centric model.

The traditional urban economic theory relevant to the mono-centric model and to the concept of urban spatial structure is the model developed by Alonso (1964), Mills (1967) and Muth (1969), often referred to as the “A-M-M” (AMM) model. The non mono-centric theoretical approach to urban spatial structure, according to (Baumont and Gallo, 1999) is attributed to (Fujita and Ogawa, 1982; Odland, 1976; Ogawa and Fujita, 1980; White, 1976). Many empirical studies of these theoretical models are found in the literature (see Anas et al. (1998) and Mills (2000) for an excellent review of this literature).

These studies have occurred across individual cities, different city sizes and metropolitan systems in the US, Asia and Europe, and these models have also been recently estimated for cities in China (Deng et al., 2008). However, these model estimations have not been part of the Australian literature on urban spatial structure since the work of Patton (1970). Despite this, there continues to be research on understanding the formation of polycentric patterns (centres or sub-centres) and of emerging specialisations across centres in the Sydney metropolitan area in particular (Parolin and Kamara, 2003; Parolin, 2005).

The AMM model also serves as the core theoretical and empirical concept of urban land development studies within and across metropolitan areas (Paulsen, 2012), where remote sensing and satellite data are increasingly being used to examine urban growth, urban form and land use change over time (Sebego and Gwebu, 2013; Herold et al., 2005). In these studies the spatial unit of analysis is

pixel-based, and of high resolution, due to the nature of the data from remotely sensed sources.

Data derived from these sources are various metrics that can describe land use, land cover, landscape features, urban growth and urban land development, in addition to urban ecological processes. Metrics such as size, shape, density, length and contagion, and so on, have been shown by Alberti and Waddell (2000) to be important in urban modelling given their effects on the spatial pattern of land use and cover on various social and ecological processes.

Paulsen's (2012) work in particular demonstrates effective calculation of urbanised land area from satellite imagery for 300 US cities over 3 decadal observations (1980–2000) and at a 30 m resolution. In this study, the data on what is urbanised land is consistently defined by classification through the multi-temporal data sets. Paulsen (2012) then relates changes in urbanised land area to three factors - population, household income and value of agricultural land. A key conclusion of the study was that the mono-centric, 3 variable, model continues to explain 75% of the variation in city sizes and that this offers some fundamental insights into the drivers of urban land markets. It is interesting to note that McGrath (2005) who undertook similar analysis, but only using 33 of the largest US metropolitan areas, came to similar conclusions about the continued relevance of the mono-centric model. However, McGrath (2005) used the US census definition of urbanised land area as the dependent variable of study not the pixel based definition.

In spite of the successful empirical work of Paulsen (2012), his study concludes that cities and regions in fact exhibit much more spatial heterogeneity of urban form and other features than the mono-centric, 3 variable model, allows for, and that these differences need to be better understood to make the mono-centric/polycentric models richer and relevant for policy.

What Paulsen (2012) is alluding to is that urban spatial structure is a more complex phenomenon than that captured by the empirical models of the AMM approach? As Troy (2004) noted, urban spatial structure is increasingly recognized as a complex phenomenon that is associated with cities as complex and adaptive systems. The main argument of this paper is that urban spatial structure is a multidimensional concept and falls into what Skupin and Agarwal (2007) call “truly n-dimensional data”, a view also shared by Arribas-Bel and Schmidt (2011).

There are three implications of the multidimensional view of urban spatial structure pursued by this paper; one conceptual, one empirical and the other methodological. First, at a conceptual level, one must identify the dimensions that capture the complexity of urban spatial structure, and develop a conceptual model of the relations and inter-relations between and among these dimensions. A critical problem here is how to identify relevant and valid indices or spatial metrics to quantify the dimensions. Reliance on census data alone, or journey to work data alone, will not necessarily suffice to capture the multidimensional

nature of urban spatial structure. Second, and stemming from the first, are the questions, what data sets need to be derived for analysis and what should be the spatial unit and the spatial resolution of the data sets? Thirdly, we need to consider how best to approach the processing of the computed data sets for meaningful analysis, especially of the interrelations among the dimensions (Herold et al., 2005).

In considering the empirical implications first, it is important to note that not only do we need ‘truly n-dimensional data’ sets but also that the data sets should be multi-temporal in nature to capture the effects of time (Herold et al., 2003; Paulsen, 2012). This means that the data sets should be measuring indices consistently over several time periods rather than being cross-sectional. What is required are longitudinal or panel data sets over three or more decadal time periods or at five yearly census intervals in the case of Australian data (Paulsen, 2012).

Herold et al. (2005) have noted that multidimensional and multi-temporal data sets on urban spatial structure also need to be measured in a spatially consistent manner. The variables that define the metrics or indices need to be measured consistently over time, in spite of likely changes in the measurement meaning of variables if they are derived from the census or similar sources. Further, as noted by Herold et al. (2005), Alberti and Waddell (2000) and Barnsley and Barr (2000) a consistent spatial resolution and spatial unit is also a pre-requisite for these data sets. In using remotely sensed data, the spatial resolution is defined by the pixel size of the satellite data capture process – typically a 30 m resolution. However, there are other ways of sub-dividing an urban area, such as administrative boundaries (census collector districts, travel zones etc.) or a regular grid system commonly found in some urban models (Landis and Zhang, 1998; Pijankowski et al., 1997).

The spatial extent or spatial domain of the urban area under longitudinal study must also be consistently defined. Where does the urban built-up area stop in any given year and other, mainly rural or agricultural, land uses dominate? How does one handle the spatial heterogeneity in the distribution of many of the metrics? The presence of spatial autocorrelation or pattern of spatial dependency in the distribution of urban growth variables has been shown to be extensive due to the cumulative and Markovian nature of urban growth (Torrens, 2008). The trend of spatial autocorrelation needs to be controlled in the application of any models of urban spatial structure (Anselin, 1995; Baumont et al., 2004; Parker and Asencio, 2008).

In considering the multidimensional view of urban spatial structure from a conceptual standpoint, this paper postulates that urban spatial structure can be captured by a focus on four key dimensions: density, diversity, accessibility and centres (see Chapter 2 for a detailed discussion about the dimensions selected to represent urban spatial structure). The focus on these four dimensions is from the perspective of the changing location of key activities

in the metropolitan area, and the spatial interaction that these changes generate, rather than from the urban form perspective. While it is possible to consider other dimensions as well, the four key dimensions used in this paper form the main themes that highlight the investigative domains of urban spatial structure research in economics, geography and planning over the past 40 years (Anas et al., 1998; Mills, 2000).

Several studies have attempted to quantify metropolitan form dimensions in the context of understanding urban sprawl. For example, Tsai (2005) proposed and tested four dimensions – metropolitan size, density, degree of equal distribution and degree of clustering – to characterise metropolitan form or sprawl/compactness. Different metrics, such as the relative entropy of population, the Gini coefficient, Morans I, and the adjusted Geary Coefficient, were quantified and tested across 299 US metropolitan areas.

Other research that utilizes more detailed typologies of metropolitan form or sprawl include the work of Galster et al. (2001) where eight distinct dimensions of sprawl with corresponding quantitative indices for each are measured and quantified, the work of Malpezzi and Guo (2001) where seven dimensions of metropolitan form variables are quantified, and the seven indices of four sprawl dimensions quantified by Hasse and Lathrop (2003).

Arribas-Bel and Schmidt (2011), on the other hand, identified and quantified six indexes of six dimensions to understand urban spatial structure as opposed to urban form – commuting costs, density, employment concentration, land-use mix, poly-centricity and size. There are similarities/differences between the urban form and urban sprawl indices and those of urban spatial structure, mainly because urban sprawl – as a pattern of spatial growth and development – is seen as one element of a city’s spatial structure (Arribas-Bel and Schmidt, 2011). However, one characteristic that unites the above studies is that the empirical analysis generally relies on cross-section data at one point in time and there are inconsistencies in the definition of spatial unit used and the treatment of spatial scale.

As regards the polycentric component of metropolitan form or structure, Black et al. (2007) have developed metrics of changes to major employment centres over decadal time periods. They analyze census data to identify trends in employment location and in commuting patterns to centres through the use of metrics such as employment density rank size distributions, visualization of employment locations and change over time, journey to work desire lines, and employment – specific preference functions for residential locations. The spatial indicators of urban spatial structure used by Bertaud (2004) show similarity to those of Black et al. (2007) whereby daily trips, average built-up density and density profiles/gradients are used to measure important spatial characteristics. The metrics used by Bertaud (2004) and Black et al. (2007) focus on the functional characteristics of employment centres and urban

spatial structure rather than their morphological features (Veneri, 2013).

In this paper, the key objective is to understand the space-time dynamics of metrics of changes to major employment centres in Sydney over the period 1981 to 2006. The following research questions are addressed in this research: what influence do the key centres exert on employment distribution over the metropolitan area?; Are the key centres part of polycentric urban structure?; and; How accessible are these centres for the workforce and what are their respective labour catchment areas? These research questions, in turn, allow an assessment of the official centres policy in Sydney which has been a feature of spatial plans since 1948. Eleven centres have been selected for this investigation.

The contributions of this paper are twofold. First, the development and use of a high resolution data set that is temporally and spatially consistent over five time periods. As can be determined from the literature, this is the first time that such an approach has been used to examine the dynamics of the dimensions and their corresponding spatial metrics. This provides the required data for understanding the changing geography or urban spatial structure and for the specification and parameterization of models of the inter-relations among the multidimensional characteristics of urban spatial structure in the Sydney metropolitan area. Second, the research fully utilises the data storage, handling, management of data, visualisation and spatial analysis capabilities of GIS. All of the tasks performed in the methodology, and the analytical outputs, were generated in GIS without the need to develop loosely or tightly coupled routines to link non-GIS outputs with GIS inputs.

2. The study area and data

2.1. Sydney metropolitan area

This research selected the metropolitan Sydney as the case study area. Sydney, the capital city of the state of New South Wales (NSW), has developed from a penal settlement in the early 19th century to a very large city with distinctive characteristics. The harbour, the beaches, the rivers, the mountains, the home gardens with big backyards and the large tracts of natural bushland make it unique among world cities (Spearritt and DeMarco, 1988). Understanding how this city has been growing and foreseeing the future direction of its growth is of primary concern to urban planners, urban geographers, urban economists and all other decision makers.

In this research, the selection of study area boundaries has been a challenging exercise. The main reason was access to the same spatial data for whole selected time period of the study that covers the Sydney metropolitan area in its largest development expansion. We will explain about the selected time period of this study later.

After several revisions, the final boundaries selected for study area are shown in Fig. 1. Yellow lines in the upper

image show the selected study area's boundary and the lower images show the geographical position of this area in New South Wales (NSW) state and Australia. The selected region, which is close to CCR boundaries, comprises the continuously built-up areas of Sydney from 1981 to 2006. The study area boundary is around 3340 km² and includes the majority of the built-up areas in the Sydney basin.

2.2. Resources of data

The main data resource of this study is census data, which is generated every five years by the Australian Bureau of Statistics (ABS). The basic spatial unit for collecting census data is the Census Collector's District (CD), which is the smallest geographical area defined in the Australian Standard Geographical Classification (ASGC). On an average, there are about 250 dwellings in each CD in urban areas, whereas in rural areas the number of dwellings per CD reduces as population densities decrease (Australian Bureau of Statistics, 2006).

Although census data have been published at CD level since 1966, no data illustrating the geographical boundaries of CDs in digital form for the earlier census data from 1966 to 1976 were found. Selection of the time period is based on the availability of consistent data for early periods. The time period selected for this study is between 1981 and 2006. The time period selected for this study is between 1981 and 2006. This period corresponds to the earliest and the latest census years for which consistent data was available. Because this research was mostly accomplished in the period of 2010–12, it was not possible to include 2011 census year in this study. To increase the accuracy of analysis and improve reliability of outcomes, it was tried to add as many time slices as possible to the selected time period. Rather than using the starting and ending years, and considering five year intervals between census dates, four other time points, 1986, 1991, 1996, and 2001, could be added to the analysis. But due to the lack of reliability of digital census data in 1986, this year was excluded from the list.

In short, the time period of this study covers 25 years from 1981 to 2006 and includes five snapshots, 1981, 1991, 1996, 2001, and 2006. The analysis methods are applied to these five time slices.

3. Methods of analysis

3.1. Boundary making

To overcome the problem of working with different boundary zones and their attributes, it was necessary to find a way to unify the format of the spatial data. The method selected in this study is to convert the spatial data into one unified grid format after generating the layers of information in the original boundary zones. Therefore the study area has been divided into a group of uniform

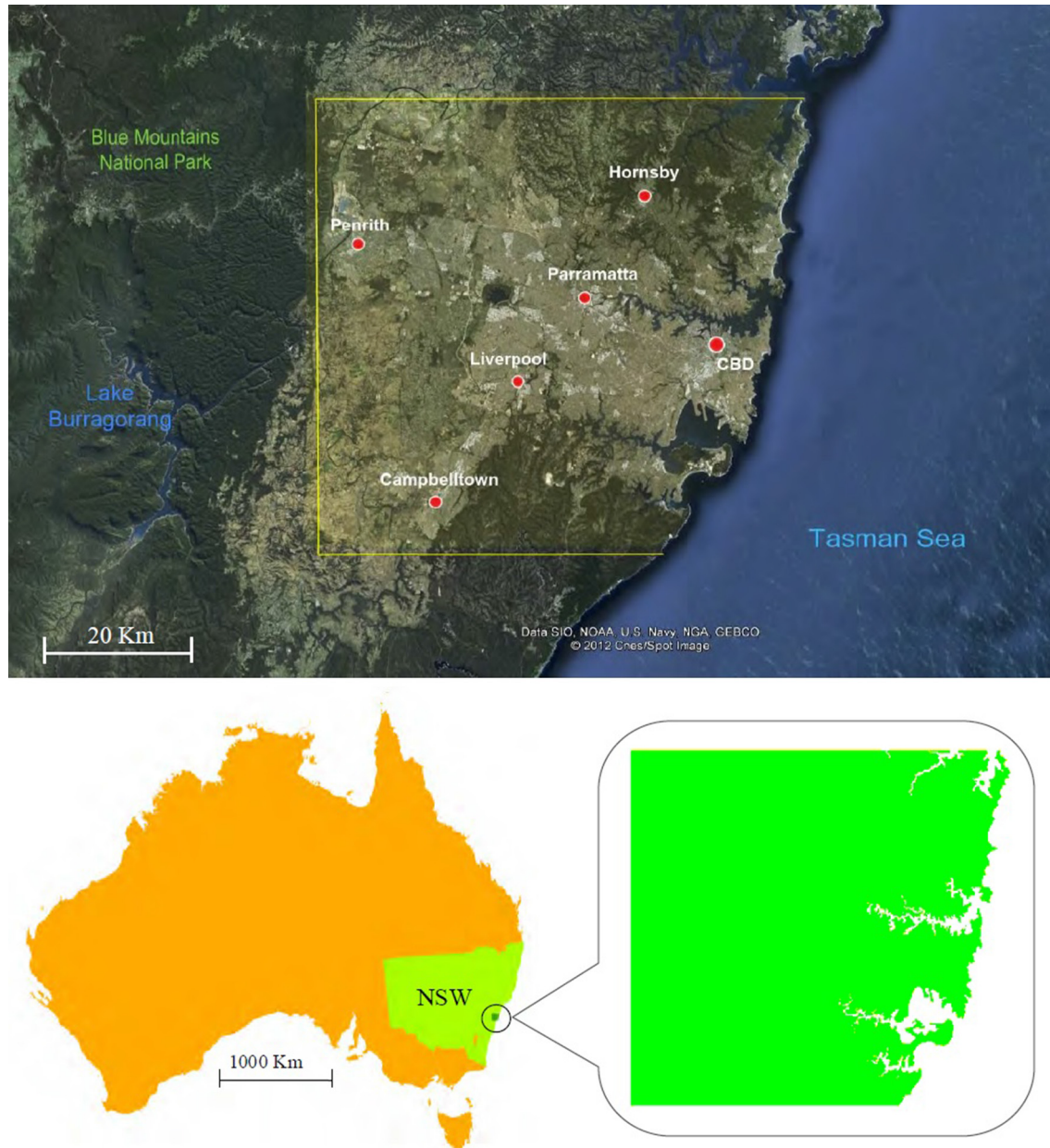


Fig. 1. Metropolitan Sydney and the boundary of study area, Source: Authors.

square cells with a resolution of 500 by 500 m. The study area in this grid format consists of 13,340 cells. This layer has been used as a “mask” in ArcGIS for conversion from polygon to raster format.

In selecting the size of grid pattern cells, two factors were considered. First, the average size of polygons (zones) in the original maps was assessed. The average size of zones varies from 49 to 671 ha for ABS boundaries in 2006 and TDC boundaries in 1981 respectively. Therefore, the size of 25 ha (500 by 500 m), which is lower than the smallest average, would be fine enough for this study. Second, is the accumulated error that appears in attributes when converting from polygon to raster format. By decreasing the cell sizes, the error decreases but, at the same time, the size

of attribute information is enlarged which is not desirable. To optimize the cell size, the conversion error was tested for several cells sizes to find out which would be the greatest cell size with an acceptable level of error.

ABS and TDC use different and incompatible zoning systems, and their boundary zones have changed constantly across the census years. ABS collection districts (CDs) are relatively much smaller than the TDC travel zones (TZs). Two different data resources multiplied by five census dates makes ten different layers of boundary zones. Fig. shows four samples of ten boundary zones, belonging to ABS and TDC zoning systems, in two pairs of images. Images A and B present the ABS collection districts (CDs) in 1981 and 2006, and images C and D present the

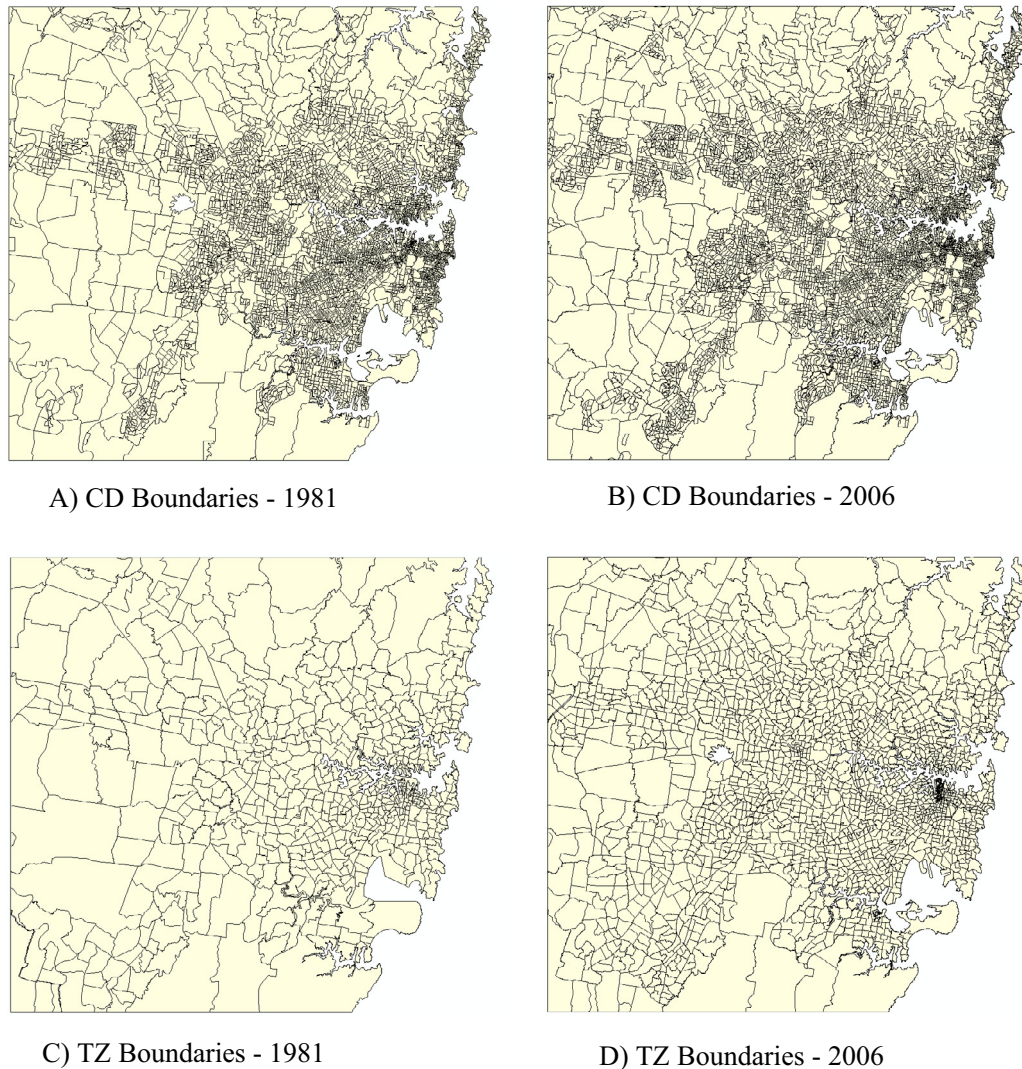


Fig. 2. A comparison the boundary zones as applied by ABS and TDC, Source: Authors.

TDC travel zones (TZs) in the same years. The shapes of six other boundary zones related to 1991, 1996 and 2001 are between these extremes. Fig. 2 shows the number and the average size of zones belonging to these two zoning systems in different years, and includes total zones that are completely or partly located inside the frame of the study area boundary. Both shapes and numbers confirm the large differences between the average sizes of zones when one applies ABS and TDC zoning system. It also shows the continuously increasing number of zones through time in both zoning systems. This has been the main reason for unifying the zones into a grid format, which will be explained in detail later.

3.2. The selection of activity centres

Eleven centres have been selected based on two criteria. The first five selected centres (CBD, North Sydney, Parramatta, Liverpool, Penrith) have been at the top of the centres hierarchy in planning documents, especially since

1988. Nevertheless, these five centres are not the only employment concentrations in the metropolitan area. Further spatial and statistical analysis identified the existence of other employment clusters which can be considered as other important centres.¹ Through this analysis, six other centres (Inner city, Chatswood, Macquarie Park, Bankstown, Blacktown and Hornsby) are selected. It is important to stress that a centre in this study is not just an employment node made up of one cell, but a larger area which has the characteristics of a bigger suburb.

To define the boundaries of eleven centres, the employment density of zones that shape each centre is assessed in five time slices. The method by which the zones which represent each centre are best defined is the assessment of decline in density value as one moves farther away from central zones with the highest density. This assessment considers all five time slices together to keep the area and boundaries of each centre as similar as possible.

¹ The explanation of this process is skipped.

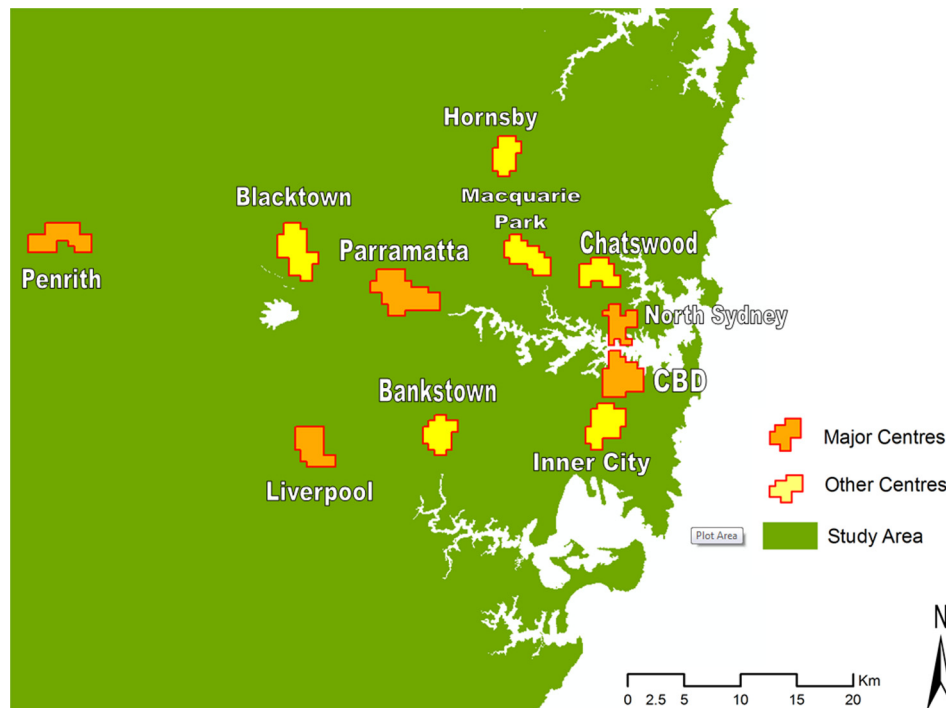


Fig. 3. Eleven selected centres and their defined boundaries in grid format, Source: Authors.

Fig. 3 shows the defined boundaries of the eleven selected centres in the study area. These orthogonal broken lines follow the 500 by 500 m grid pattern and encompass highly concentrated employment zones around each centre. The defined boundary includes the commercial centre and other contiguous high employment density cells. To make it possible to compare the trends of change in the centres' structure, the shape and location of these boundaries is kept fixed across the five census years.

3.3. The dominance and influence range of centres

The domination of each centre is measured by the size of employment at respective centres. Calculating each centre's share of total employment in the study area, or the sum of employment in the selected centres is a complementary analysis that provides a better understanding of each centre's strength.

The structure of trip flow toward a centre can define some important external characteristics. The number of journey to work trips to each centre is almost the same as the number of jobs in each centre and does not produce more information. But the distribution pattern of trip origins in the metropolitan area can indicate the influence range of each respective centre.

A metric is developed which combines two factors, trip characteristics (trip length and frequency) and the size of areas where the trips originate, to make a circle of influence which has equal geometric characteristics. Fig. 4 shows the concept of measuring the influence range of a centre by an equivalent circle. The scattered squares represent the areas having trips to the centre. The sum of the product of the square areas

by their distance from the centre ($\sum_i^A d_i$) gives a figure which potentially explains the influence range of the centre. This figure is converted to a shape of an equivalent circle through a geometrical method. In this method, for a given circle with radius R which is divided into numerous tiny areas, the integral of the multiplication of those small elements by their distance from the centre is calculated by $\frac{2}{3}\pi R^3$, when the size of elements goes to zero. By combining $\sum_i^A d_i$ and this formula in an equation, we obtain R , the size of the circle. This means that if whole trips are evenly distributed on the surface of this circle, it would have the same affect.

3.4. Employment preference function

In transport analysis, a preference function is an aggregate of the travel behaviour response by a zonal grouping

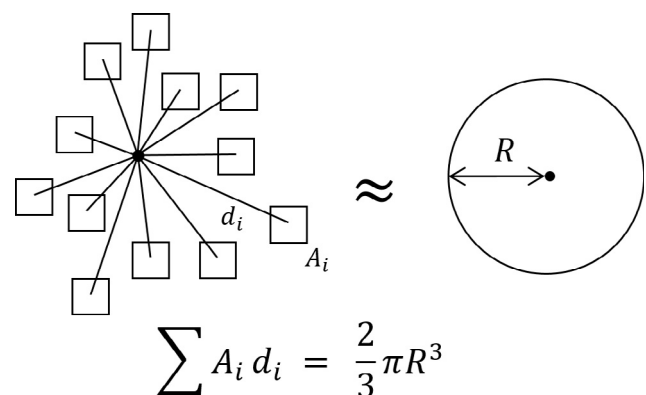


Fig. 4. Measuring the influence range of a centre by an equivalent circle.

given a particular opportunity surface surrounding those travellers (Suthanaya, 2011). A journey-to-work preference function is the relationship between the proportions of travellers from a designated origin zone who reach their workplace destination zones, given that they have passed a certain proportion of the total metropolitan jobs.

The slope of these empirically determined preference functions tells us much about travel behaviour as a pure response to land use opportunities, and not to transport impedance (distance, time or cost, depending on data availability) as in the gravity model. The residential location specific travel preference function is the propensity of travellers to take up nearer or further-away job opportunities compared to lower or upper bounds that can be uniquely specified. Zonal functions with steep gradients will imply a preference of those resident workers for shorter commuting (given the opportunities available), whereas those with shallow gradients will imply a preference for longer trips (Cheung and Black, 2005).

4. Findings

4.1. Population and employment characteristics of the centres

Both population and employment density in centres, as expected, are higher than the average density of those variables for the whole metropolitan area and this gap is much larger for employment density.

Among the eleven centres, the CBD demonstrates a significant difference in all specifications compared to other centres. The highest population and employment density can be found in the CBD. The growth in population in the CBD was associated with a large apartment boom – a boom which has continued beyond 2006 (Shaw, 2006; Tsutsum and Parolin, 2011). Employment density in the CBD, as expected, far exceeds the density of other centres; it grows from 230 jobs per hectare in 1981 to 282 in 2006. The CBD alone, by excluding 1981, shares almost 18% of total employment in the metropolitan area, which in comparison to its size is around 0.6% of the built-up area, a very large concentration of activities in a relatively small area. The intensive employment densification of the CBD is associated with growth in service jobs.

The most of the centres experienced continuous growth of population and employment over the 25 year period of the study. The eleven centres together share around 37% of total employment and 9% of total population of the metropolitan area. These are the average rates of five census years which have a low deviation across the 25 years.

The employment to population ratio can give a better understanding of centre characteristics. The CBD has the highest rate with an average of 3.4 across five census years, followed by the Inner City with a rate of 3. This rate is 1.7 for Parramatta, 1.6 for North Sydney, 1.5 for Macquarie Park and 1.1 for Chatswood. Other centres have a rate below 1.0 and the lowest rate (0.5) belongs to Bankstown.

The average rate of employment to population for the whole metropolitan area is 0.4, which can be considered as a threshold that implies that if a centre has a higher rate than 0.4, there is greater excess of jobs relative to local workers and, therefore, a demand for workers from outside the centre to commute to jobs at the centre. The higher rate also indicates a larger catchment area of commuters for the centre. This is highlighted in a later section through analysis of journey to work trips.

4.2. Measuring the strength and dominance of the centres

There are different measurements which can define the strength or the degree of dominance of each centre. In this study, the total employment at each centre has been used for measuring this factor.



Fig. 5. Dominance indexes for eleven centres.

To compare the strength of centres, two metrics (called dominance indices) are introduced. The first index is based on the total employment in each centre and the second index is based on the each centre's share of total metropolitan employment across each of the five census years. Fig. 5 presents the results of this analysis. The two dominance indices are scaled between 0 and 100, where 100 is allocated to the highest value and other values are calculated proportionally. For index one, which indicates the size of employment in each centre, the CBD in 2006 has a value of 100 and for index two, indicating each centre's share of total metropolitan employment, the CBD in 1981 has the highest value. Both dominance indices indicate four levels of ranking among eleven centres. The CBD stands in the first position and is separated from the others by a large gap; North Sydney, Parramatta and Inner City take the second rank; Chatswood, Macquarie Park and Liverpool can be ranked in third position and finally Penrith, Bankstown and Hornsby take the lowest rank. Among the centres; Inner City, Bankstown and CBD have the lowest growth rate and Macquarie Park, Chatswood and Penrith have the highest growth rate across the 25 years of the study period.

4.3. Influence range of the centres (using journey to work trips)

In this section the connections to each centre and the range of its influence to other parts of the metropolitan area are investigated. For this purpose, journey to work trips are used as the main data source for generating the necessary information.

The literature suggests that urban spatial structure at the metropolitan level has significant impacts on the travel patterns of residents or workers. On the other hand, the emergence and growth of employment centres appears to be a part of the larger decentralisation phenomenon (Giuliano et al., 2011). In this way, each designated centre hosts a number of employed persons who commute from their residential area to that centre for work. Stronger centres attract more work trips from farther distances across the metropolitan area.

The density of trips to each centre increases with closer distance to the centre and decreases with increasing distance from the centre. The rate of decrease in population and employment density is likely to be a steep gradient with distance from a centre.

By comparing 1981 and 2006, it appears that all centres, but especially Parramatta, Macquarie Park and Chatswood have been expanding their influence range by attracting more people from broader areas to work in these centres. The map of the CBD shows the densification of trip flows around the CBD over the 25 year period of the study and this suggests that the majority of additional employed people in the CBD are found in areas closer to the centre. North Sydney influences larger areas to the south of the harbour in 2006 compared to 1981, and Parramatta extends its influence towards the west and

south west. The Inner City catchment area doesn't show much change from 1981 to 2006, but Macquarie Park and Chatswood present a huge circular expansion during this period. Other centres like Liverpool and Penrith, while experiencing a noticeable growth of labour catchment area, still have an influence range that remains very local (Fig. 6).

4.4. Measuring the influence equivalent circle of each centre

To quantify the influence range of centres in a comparable way, a method which combines trip characteristics (trip length and frequency) and the size of areas from where trips originate, to generate an equivalent circle with the same conceptual geometric effect. The size of the circle represents the influence range of each centre. Table 1 shows the radius of each circle calculated for the eleven centres for 1981 and 2006.

Based on the radius of the influence equivalent circle, all centres appear to be spreading their influence range over the 25 year study period. The CBD, with the largest influential circle, has experienced the second least growth after Bankstown over this period. Parramatta has the second largest influential circle after the CBD, followed by North Sydney and the Inner City. Macquarie Park has the largest growth rate and Penrith takes the second rank in this regard.

It needs to be mentioned that the influence circle of a centre is a conceptual image to give a comparable tool for understanding the influence level of each centre and does not visualize the real catchment areas or overlapping parts.

4.5. Density profile of the centres

Fig. 7 presents the distribution pattern of trips to the five major centres using density profiles. Each of the three images, related to years 1981, 1996 and 2006, visualizes the density profile of trips to these five centres. The other six centres are excluded from the diagram to avoid confusion of many lines in the lower density parts. Density profile graphs were generated for the whole study area and from a west-east view.

The density profiles of trips to the CBD are far above the profile of other centres; this indicates a higher number of trips to this centre, as expected, compared to other centres. The CBD's density profiles for three census years show some densification close to the CBD and little change in other parts of the profile. North Sydney and Parramatta profiles for the three years show a gradual upward growth, not only near the centre but also in broader areas far from the centre. The Liverpool and Penrith profiles indicate more local growth over the 25 year period.

5. Conclusion and discussion

The aim of this paper was to understand the space-time dynamics of metrics of changes to major employment

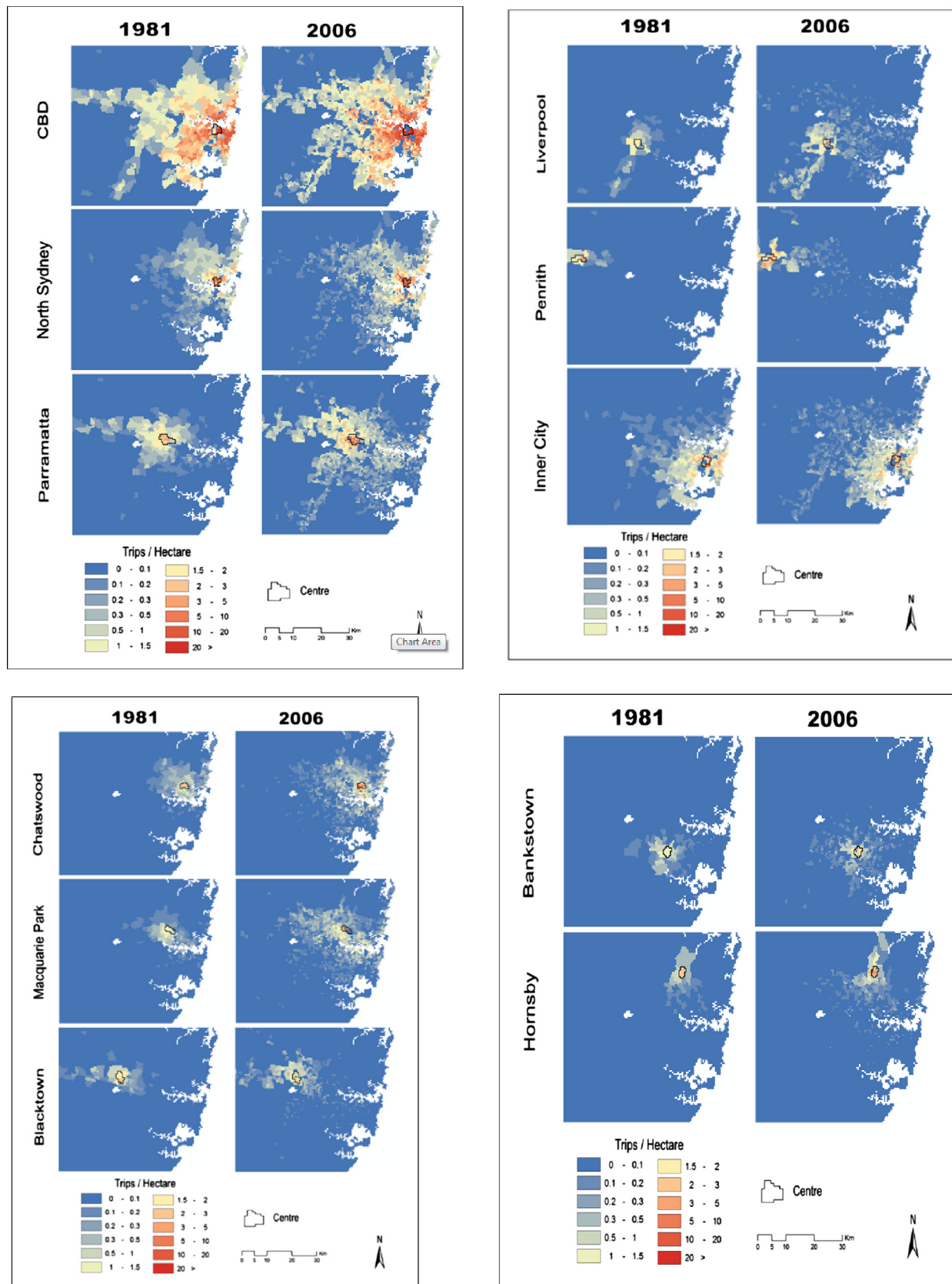


Fig. 6. Flow of trips to eleven centres in 1981 and 2006.

Table 1
The radius of influence equivalent circle for eleven centres (km).

Centre	1981	2006	Change of circle radius (percent)	Change of circle area (percent)
CBD	24.9	26.2	5	11
North Sydney	12.8	14.8	16	34
Parramatta	11.4	15.3	34	80
Liverpool	8	10.6	33	76
Penrith	6.3	9.2	47	115
Inner City	13.2	13.9	6	12
Chatswood	8.1	10.7	31	72
Macquarie Park	7.7	11.5	48	120
Blacktown	7.8	9.0	15	32
Bankstown	6.9	7.1	4	8
Hornsby	6.2	7.6	24	53

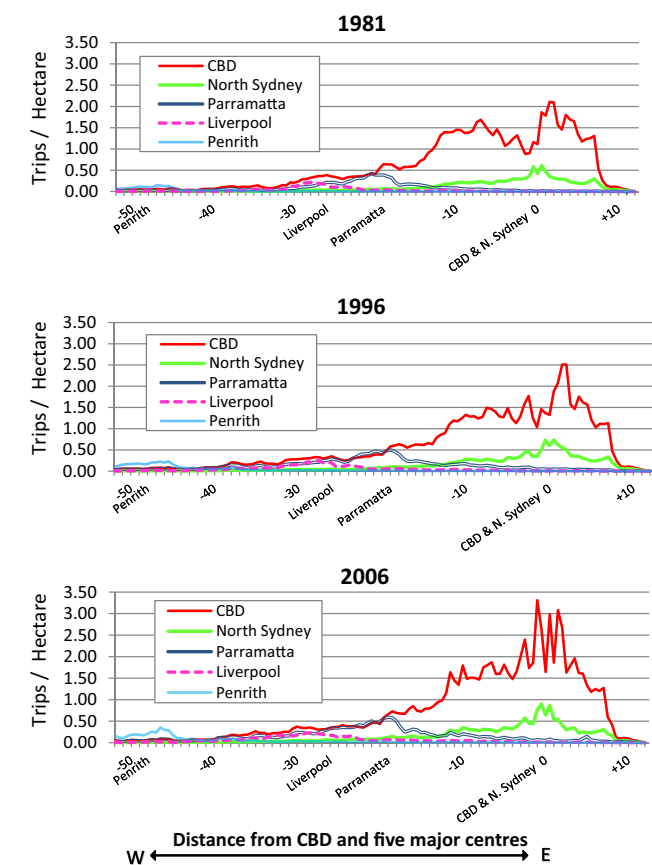


Fig. 7. Density profile of trips to each of five major centres in 1981, 1996 and 2006.

centres in Sydney over the period 1981 to 2006. The analysis of the role of centres included rank size distributions, maps of journey to work trips to the centres, influence circles of centres, employment preference functions and tabular data on levels of employment. The paper was successful to document changes in the spatial distribution of the main population and activity centres and their associated metrics (indices), and to capture the space-time dynamics of these changes - the following findings emerged.

The findings on accessibility to employment indicate that fewer areas are undertaking shorter trips (less than

17.5 km in length) and more areas are undertaking trips above 17.5 km in length). Home to work trip lengths have increased in CBD and inner city residential areas and in the suburbs as well as journey to work trips follow more dispersed employment locations between 1981 and 2006. However, a larger part of Sydney has experienced a decline in average trip lengths between 1981 and 2006, indicating overall improvements, on average, in accessibility of home to work trips.

The results of the analysis indicate that, apart from the CBD, North Sydney and Parramatta, the remaining centres appear to exert little influence on employment distribution over the metropolitan area. The CBD and North Sydney continue to grow at high levels compared to the other centres. Parramatta, Chatswood and Macquarie Park have grown relatively slowly over the study period and the performance of other centres has been very modest at the same time. Only 37% of employment in the metropolitan area is located in these eleven centres, which means that 63% is distributed in other smaller centres and in non-centre locations dispersed in lower density places around the metropolitan area. According to newly published information, Australian capital city centres have captured nearly half of all new jobs created across the nation in the past 10 years, signaling the failure of policies to promote decentralisation and driving disenchanted regional voters to minor parties (The Australian, 2017). On reason is that CBDs have already enjoyed better transport connections to economic hubs.

It appears that only the CBD and North Sydney continue to exert an important influence on employment distribution over the metropolitan area. These centres will continue to develop their influence as the “global arc” is reinforced by the Metro Strategy. Parramatta is the second CBD and will also grow as a result of the Metro Strategy. The remaining centres are likely to find it difficult to compete with more dispersed employment density distributions and their performance as polycentric nodes is likely to be limited as a result. To answer the second question, the evidence for a strong polycentric structure in the metropolitan Sydney does not appear to be present.

The evidence presented indicates that the centres have well defined spatial labour markets, even though most overlap to some extent. These centres are accessible for the workforce, and appear to have become increasingly more accessible as a result of improvements in transport infrastructure. As a result, their influence range has expanded over the period of the study.

A significant conclusion is that urban spatial structure in Sydney can be clearly characterised as multi-dimensional as opposed to being treated as uni-dimensional. The mono-centric characteristics of employment distribution suggest that ‘distance from the CBD’, in particular, remains a key influence on how population and employment has been structured in the metropolitan area, but there are other metrics that also affect this distribution. This is contradictory to the finding of a similar study on Beijing spatial

structure which found the agglomeration economy still plays a dominate role, and so planning interventions and heavy public investment in decentralized development may result in a loss of economic efficiency (Huang et al., 2015). Another study of employment centres in Seoul showed that the pattern of spatial distribution of employment differs by industry, represented by centre-oriented, CBD-oriented and non-centre-oriented industries (Kim et al., 2014). This paper did not examine other influences such as the role of transport networks and terrain, but these are also important influences on urban spatial structure.

The analysis of the multi-dimensional structure of the housing and activity centres showed that Sydney has both strong mono-centric and weak polycentric characteristics for population and employment density distributions. The concentrations of population and employment in the core areas between 1981 and 2006 have reinforced the role of the CBD and inner areas to a level never before experienced in the urban history of this city. The key polycentric nodes outside the CBD only exert a minor influence on the population and employment surface of the Sydney metropolitan area.

The modelling analyses undertaken for this research highlight the reasonably strong effects of the metrics on population and employment density distribution. These require even more detailed analysis in the future, and there is a need for these inter-relations to be better understood by local and strategic planners and policy makers.

Many planning policies have tried to build up centres. For example, the 2005 Metro Plan was the City of Cities. The outcomes of this paper would suggest that this sort of plan would be difficult to implement. The whole “30 min city concept” has been a planners dream for many years but this paper suggests it might be a pipe dream. This finding could be interesting for practising planners as the implications of this paper.

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