Dynamics of clustered employment growth and its impacts on commuting patterns in rapidly developing cities

Pelin Alpkokin a,*, Charles Cheung b, John Black c, Yoshitsugu Hayashi d

a Istanbul Technical University, Faculty of Civil Engineering, Transportation Division, Maslak, TR-34469, Istanbul, Turkey
b Steer Davies Gleave, 28-32 Upper Ground London SE1 9PD, United Kingdom
c School of Civil and Environmental Engineering, University of New South Wales, Sydney, NSW 2052, Australia
d Nagoya University, Graduate School of Environmental Studies, Nagoya shi 464-0814, Chikusaku Furouchou, Japan

Received 13 October 2005; accepted 12 November 2007

Abstract

Trends in suburban clustered employment growth (poly-centric development) occur large cities. Decentralized employment growth is complicated and subject to many factors. In fast growing cities of the developing world analysis is rarely undertaken when formulating master plans or spatial plans. An analytical framework of research aims, suitable techniques, and outcomes for policy analysis are described. Its practical utility to identify clusters and their dynamics is explored with available data for 1985 and 1997 for Istanbul. Impacts on commuting patterns (trip lengths, employment destination zonal preference functions and mode shares) are analyzed for each type of sub-center identified in Istanbul, and some findings contrasted with North American cities where such research into the dynamics of employment clusters has been undertaken. © 2007 Elsevier Ltd. All rights reserved.

Keywords: Clustered employment; Sub-centers; Commuting

1. Introduction

Our focus is on rapidly growing cities of developing countries where the dynamics of spatial structure and re-structuring are less well understood than in many Western countries. As the cities get larger, an urban form that diverges from a mono-centric city to a rather more complex spatial pattern of employment clusters would be expected. Early research into employment location in the mono-centric city (for example, Alonso, 1964) has given way (Anas, 1987) to the observation of a different form of metropolitan structure where offices and firms tend to cluster in sub-centers. Since then, with rising interest, a considerable number of empirical and theoretical studies have appeared on non-mono-centric structures, mostly for American cities (Giuliano and Small, 1999; Hughes, 1991; Gary, 1990). This paper contributes to research on multi-centric employment centers by proposing a conceptual analytical framework suitable for application in developing countries. It illustrates the
general approach with particular reference to Istanbul – a large city (11 million population) straddling Asia and Europe and also the largest settlement of Turkey.

The methods described and illustrated in this paper provide a more rational basis for analyzing the dynamics of sub-center formation and impacts on commuting patterns for large and growing cities. To our knowledge there is no comparative study to those for US cities of the large cities of the developing world and their non-mono-centric urban dynamics. The issue in developing countries is that such dynamics of change have not been studied, yet planners intuitively propose for metropolitan structure plans (spatial plans) the location of future employment nodes on a map without resort to much rigorous analysis. Land-use regulations are often weakly enforced (although, generally, historical centers have been preserved, and some outstanding natural features have been protected) which lessens any chance of the plans having any effect on spatial re-structuring. These cities differ from those in the US as the length of freeways per inhabitant is much lower. Although auto ownership and income is currently much lower, rapid growth of population and the economy suggest high future auto usage, unless it is deliberately constrained in the case of Singapore and Hong Kong. The outcome is a dispersed city that becomes more auto-oriented and unsustainable (Newman and Kenworthy, 1999). Dispersal compromises the opportunity of any rail investment, or even dedicated bus networks, to support the growth of sub-centers by increasing public transportation mode shares and shortening journeys compared with a mono-centric employment pattern.

First, we outline the main characteristics of a non-mono-centric urban spatial structure. We then propose an analytical framework that may be applicable to any large metropolitan region where we raise the question as to the objective of each analysis suitable techniques available to the planners where there may be limitations on data, and what such analyzes might show (output). This framework is illustrated with a case study of Istanbul’s employment cluster dynamics from 1985 to 1997 (Section 4). Section 5 analyzes transportation in more detail by concentrating on commuting to the employment clusters. Changing patterns of commuting trips and the level of transportation provision to the emerging sub-centers are discussed to contrast to the findings in US cities by Cervero and Wu (1997, 1998), Cervero et al. (1999), Giuliano and Small (1999) and Gordon et al. (1986). Average trip times, modal splits and accessibility indices separately for public and private trips are examined for different employment clusters. The argument is that as multi-centric structure becomes dominant, longer and more auto trips are likely to occur. Finally, the conclusions suggest topics for further research.

2. Non-mono-centric urban structure

The defining characteristics of the non-mono-centric city are the CBD is still the strongest center, but it loses its share of relative metropolitan employment, and its absolute growth is slight when compared to growth elsewhere in the region. Such an emerging urban structure can be classified into two main categories: dispersed employment; and locally-centralized employment (Gary, 1990). In the first, economic activities are rather scattered, and the employment density gradients are somewhat flat outside the CBD. In the second archetype, there is an urban pattern where firms and businesses are clustered, either in some sub-centers (poly-centric employment development), or along major transportation corridors (rail or highway), where local density gradients are observed, or indeed with both, as the case of Sydney, with its “global arc” following the airport rail line through the CBD to Chatswood, plus other poly-centric employment centers (such as Parramatta or Liverpool).

White (1999) has suggested three main reasons why clusters occur. One is the concept of agglomeration economies, or external scale economies. Many studies have examined these agglomeration benefits enjoyed by each economic unit that leads either to the CBD planners and Chambers of Commerce pursuing its role as the strongest center, or to other alternative local centers not being promoted (for example, see, Cervero et al., 1999; McMillen, 1999; McDonald and Prather, 1994).\(^1\)

\[^1\] It is generally given in the form of accessibility – predominantly gravity-type accessibility – amongst the firms as given by the equation below, where \(A(x)\) is the agglomeration benefits enjoyed by firms at location \(x\) due to the proximity to employment concentration \((E_y)\) at location \(y\).

\[ A(x) = \int E_y \exp^{-d(x,y)} dy \]
The second factor is that as the city gets larger the CBD reaches to its physical capacity to accommodate more employment. Centralized land prices are forced upwards with demand pressure. Land availability and price in the outer suburbs are attractive features, especially for the new firms who locate outside of the CBD but also for those firms re-locating (Heikkila et al., 1989). Henderson and Mitra (1996) analyzed the location choice of a land developer to develop a sub-center at a distance from the core city by varying the core city capacity.

The third factor is a transportation-related issue—primarily the commuting cost of the labor force and the transport cost of the products that are exported from an export node that could be either the CBD or a sub-center. This idea formed the ground for a growing number of theoretical challenges to develop models simulating the firms’ behaviors when there are alternatives to a CBD location. In such models, firms are treated as units that are seeking to maximize profits that differ spatially with the varying external scale economies, land rents, and commuting costs. The wage rate that a worker residing in the suburb may accept to be paid by a suburban firm is less than that by a CBD firm because of a reduction in the commuting cost (Fujita and Ogawa, 1982).

Another group of models used discrete choice type of modeling through multinomial logit specification, taking each zone and calculating profits separately. Among such, Shukla and Waddell (1991) incorporated a vector of non-monetary spatial characteristics into the given profit function, such as distance to the CBD, the airport, or to a major highway intersection. However, transport diseconomies in terms of traffic congestion have received less attention except in a few studies such as McMillen and Stefani (2003). They tested the 62 American cities and found that two important variables explain the sub-center formation by almost 80%. These are population and commuting costs defined as the travel time index which is the ratio between average and peak hour trip time.

### 3. Analytical methodology

The literature review has identified that a number of empirical studies on US cities and theoretical modeling challenges on sub-centers have been presented, but, to our understanding, there is no one convenient reference on analytical methods on which to base an investigation. This lack of a general analytic and systematic methodology covering all relevant issues is most acute when formulating planning schemes for growing cities in the developing world where precise land-use and transportation data are sometimes lacking. We propose a five-step methodology for analyzing multi-centric urban form, within a framework of study purpose and aim, the appropriate analytical technique(s), and the expected outcome for planning and policy, as simplified in Fig. 1.

#### 3.1. Identifying employment clusters

First, we show how to define employment clusters in any city. This is crucial to any research investigation because different findings on the number of clusters are likely for the same data set with different classifications, as noted for some American cities. The recent tendency is to define sub-centers as the contiguous set of small census tracts, each with a minimum density where, all together, a minimum total employment cut off is reached. The methodological problem is that this cut-off has varied for different cities. A further classification is then achieved according to some locational and employment specific characteristics, such as edge city, or post-World War II suburban development, that are not necessarily ranked (McMillen and McDonald, 1998).

Our methodology is a simple and generalizable way of clustering the employment locations, particularly when the data are more aggregate, with medium or large-scale traffic analysis zones. Gross employment density is proposed rather than net employment density in order to omit the very small local density peaks that may lead to wrong conclusions, as also noted by McDonald (1987). Gross values are also preferred because different land-use functions other than employment may also have a potential capacity for accommodating economic activity in the future.

---

2 Minimum employment per gross acre and minimum total: for Los Angeles 10 and 10,000 (Giuliano and Small, 1991) also 20 and 20,000 (Small and Song, 1994); for San Francisco 7 and 10,000 (Cervero and Wu, 1997); and for Cleveland 8 and 5000 (Bogart and Ferry, 1999).
In order to identify the clusters of sub-centers, Zipf’s law\(^3\) of rank frequency distribution can be applied, noting that although there have been many studies adopting Zipf’s law to a rank size distribution of cities at the regional scale and national scale, there have been few at the urban level. Logarithmic employment density is plotted against rank size. One example is Giiliano and Small (1991) who found a good fit for 29 centers in Los Angeles.

The next crucial step is how to decide the number of major employment clusters and their classification through breaks of gradient. The number of clusters depends on the size of the city, the degree of detail aimed at in the analysis, and also the sizes of the tracts or zones. As the data are plotted as a two-dimensional graph, simple techniques of “cluster analysis” (Kaufman and Rousseeuw, 1990 and Anderberg, 1973) are appropriate. These are correlations between the variable and the rank using the Pearson coefficient, equal intervals, and similarities of Minkowski distance\(^4\) between the variables, or maximizing the Spearman rank correlation (see

\[^{3}\] R\(^x\) x S\(^r\) = K. When plotting the diagram for natural logarithms of size (S) and rank (R), a log-linear pattern is observed. When the slope equals –1 it is known as Zipf’s law.

\[^{4}\] d(i, j) = \[\sum_{q} |x_{i1} - x_{j1}|^{\frac{1}{q}}\] is simplified for one dimension and becomes

\[d(i, j) = |x_i - x_j|\]

where x is the logarithmic employment density on the y-axis.

---

**Fig. 1.** A scheme for analyzing multicentric urban dynamics.
Section 4.1). Data groups are searched that each give a best fit for linear correlation between logarithmic employment density and rank within themselves using the Pearson correlation coefficient. Once the main clusters are decided by Pearson coefficients further classification can be done, either by following equal interval scales or by dividing into sub-clusters proving distance similarities. As a guide only, we note that for San Francisco, Cervero and Wu (1997) defined four tiers. Possible description of the four clusters are: cluster 1 zone as mature old centers; cluster 2 zones as rather developed sub-centers; cluster 3 zones as emerging as a sub-center; and cluster 4 zones as not necessarily now, but likely to be a sub-center in the long term. The actual number of tiers will emerge from the analysis of data.

3.2. Understanding employment cluster dynamics

Dynamics is concerned with change over time. For developing countries, in the absence of periodic census data collections, resort must be made to sampling of employment and travel, usually as part of land-use and transportation studies. Examining the clusters with the available data for two (or more) time points is needed to understand the change in job location patterns, and the embryonic emergence of some new sub-centers. Conceptually, we are comparing how locally peaked, or flat, a distribution is from the CBD over time. A number of simple descriptive statistics, such as zone frequencies in clusters, ratios for cluster shares over the total, or employment density gradients, can be used.

A Lorenz curve drawn for the cumulative area and the cumulative employment also tells something about the employment layout. As the curve approaches to the diagonal, it indicates a more equal, or a more flat, distribution of employment over space, but does not reveal sub-centering or clustering structure and trends. For example, Waddell and Shukla (1993) plotted this for the Dallas Forth area, and Small and Song (1994) for the Los Angeles area, to prove only employment dispersion. However, the rank size distribution changes can tell us more about the pattern of growth by comparing the rank size distribution over two time periods (Fig. 2). If the increment of employment growth is exactly the same in every zone then the two distributions are similar or parallel (Fig. 2a). Other theoretical patterns are possible: smaller increments in the big centers and larger increments in the smaller zones – decentralization (Fig. 2b); larger increments in the big centers and smaller increments in the smaller zones – centralization (Fig. 2c); and the possibilities of absolute declines in employment in the larger zones (or in the smaller zones). Where stratified employment by industry-type are available, plotting the rank size distribution for different types of businesses would provide a better understanding of the industry composition changes and its possible influences on clustering.

3.3. Investigating clustered employment structure and transport system level of services

Employment clusters are located at places that often have relative locational advantage in terms of the accessibility provided by highway and public transportation. Center relative accessibility, or congestion effects, have been mentioned by researchers but have been utilized less to analyze the labor force commuting costs. The history of accessibility measures in urban planning starts with Hansen (1959), who demonstrated a relationship between urban development potential and accessibility for the Washington DC metropolitan area. Giuliano and Small (1999), following Hansen, also adapted the simple gravity-type accessibility model in
its general exponential form, where \( A^L_i \) is the accessibility of zone \( i \) in question; \( L_j \) is the labor force in zone \( j \); and \( t_{ij} \) is the travel impedance function between zones \( i \) and \( j \)

\[
A^L_i = \sum_j L_j \exp^{-\beta_{ij} t_{ij}}
\]  

(1)

They calculated the relative labor force accessibility with road-network distance as the impedance, and tested sub-center formation in Los Angeles. However, due to rather small variations in the sample from the mean, accessibility was found to have little explanatory power for clustered development. In a similar way, other forms of impedance are appropriate to calculate the potential accessibility of a center: peak-hour trip times or generalized costs to incorporate the opportunity cost of traveling in the rush hours. Cervero et al. (1999) also examined the gravity-type accessibility changes between 1980 and 1990 for the San Francisco Bay area. Because the region is served predominantly by buses, using the same highway network as cars, they did not include mass transit. However, when considering public transportation, the out-of-vehicle time (closely related to reliability and punctuality) is relevant for public transportation accessibility. Therefore, we strongly recommend in our framework the investigation of labor force accessibility separately for auto and for public transportation.

One suitable way of calculating the potential accessibility by public transportation is to use the accessibility indices pioneered by the London Borough of Hammersmith and Fulham (1995). The model provides the basis for calculations of public transportation frequencies and the level of public transportation provision across any specified study area given by the following equations:

\[
X = \text{walking time} + 60K/2S
\]

(2)

\[
M_i = 30/X_1 + 15/X_2 \ldots 15/X_m + 30/Y_1 + 15/Y_2 \ldots 15/Y_n
\]

(3)

where \( X \) is the access time (that is from the doorstep to public transportation); \( X_1 \) and \( Y_1 \) are access time to the most accessible bus route and rail station; \( m \) and \( n \) are the number of accessible bus routes and train stations; \( S \) is the number of scheduled services per hour, and \( K \) is the reliability factor (peak travel times in inner London \( K \) were taken as 1 for rail and 2 for bus).

The \( M_i \) accessibility index in its original form is really a measure of the frequency involving reliability and availability of the services. However, the peak hour in-vehicle time is not embodied in the index. Therefore, in order to incorporate the congestion effects it is also necessary to calculate different means of accessibility by adding the peak-hour trip time to the access time in Eq. (2) and calculating a gravity-like accessibility index as given by Eq. (4). Then, the trip time between each pair of zones becomes the sum of the \( t_{ij} \) – in-vehicle trip time; and \( X_{ij} \) – access time to the public transportation network for the trips starting at zone \( i \) and ending at zone \( j \).

\[
A^L_i = \sum_j L_j \exp^{-\beta_{ij} t_{ij} + X_{ij}}
\]

(4)

We note that both the original and revised Hammersmith and Fulham indices can be used depending on data availability. But using compatible accessibility indices for the total of the trip given by Eqs. (2), (3) and (4) for highway and public transportation will capture the discrepancies of transportation service provision for spatially varying employment agglomerations, and shed light on the impacts of future transportation policies.

3.4. Investigating clustered employment structure and commuting behaviors

A number of studies, although far less than compared to those on employment location dynamics, have examined the impacts of poly-centrism on residential location choices and commuting patterns, where the issues are mode shares at the employment destination, and the mean trip lengths (journey times) of those workers. There are two contrary arguments and empirical findings. With a decentralized employment and spatial mismatch, cross commuting increases, resulting in more wasteful, or excess, commuting in terms of longer distances traveled. Dubin (1991) discussed as cities get larger in terms of area and population, they might produce more cross commuting for mono-centric cities than in poly-centric cities, as the workers will possibly tend to
reduce their commuting time by taking opportunities provided by a multi-centric structure. This was discussed for hypothetical urban spatial structures by Black and Katakos (1987) who examined the upper and lower bounds to commuting travel based on distance minimizing and distance maximizing behaviors of workers.

Gordon et al. (1986) found similar results for Los Angeles as to Dubin, but Cervero and Wu (1998) showed that, for San Francisco between 1980 and 1990, the average trip distance and time increased by 12% and 5%, respectively. However, Gordon (1991) underlined a shortened automobile commuting time over 5 years for 20 USA cities. Since the subject of commuting is quite complicated with its different components, it is necessary to analyze the cluster-specific trip distances, times and modal splits. Moreover, it is important to plot the trip length distribution and the total vehicle distance traveled of the trips attracted by the zone of the clusters (for example, see, Giuliano and Small, 1991; Cervero and Wu, 1997).

Population–employment ratios in centers have also been widely used to understand the degree of mixed land-use development patterns, especially for the housing market in poly-centric cities (for example, see, McDonald and McMillen, 1990). However, population–employment ratios when used to analyze transportation, should be the ratio between the employment in a given zone to the total population within a region of a specified radius from that zone (Alpkokin et al., 2005; Shukla and Waddell, 1991). This is a simple method to establish whether there is a relation between shorter trips and sub-centers with high population and employment ratios.

A more analytical way of grasping the residential location preferences for a given employment center is to plot graphically the destination specific employment preference functions, based on a form of the intervening opportunity model (see Black et al., 1993). The estimation of the shape of the zonal preference functions requires data for the zonal number of resident workers, the zonal number of job opportunities, the destination-origin pattern of traffic, and the inter-zonal transport impedance matrix. The estimation of the raw preference function for each employment zone is set out in the following six steps:

I. Residential worker (destination) zones are ranked in order of increasing distance from the employment zone (origin zone).
II. The cumulative numbers of labor-force workers are calculated at increasing distance from the employment zone and these are expressed as a proportion of metropolitan total.
III. From the D-O data, the number workers residing with destinations at increasing distance from the employment zone is set out.
IV. The D-O flows are expressed as a proportion by residential worker (destination) of the zonal trips attractions to the employment zone.
V. The proportions are plotted as a graph.
VI. Finally, a quadratic function in the form of \( Y = aX^2 + bX + c \) is determined for curve fitting (other functions could be employed).

For each employment zone, residential zones are ranked according to increasing distance, or better, transportation travel time, by either car or public transportation, or a weighted combination of the two away from that zone. The number of residential workers living in each zone is a proxy for housing opportunities. By plotting the cumulative distribution of residential workers reached, a housing opportunity surface around that employment zone is constructed. Steep gradients imply a nearby choice of residential location; shallow gradients around a sub-center imply a broader, metropolitan-wide, spatial labor market.

3.5. Investigating hypothetical urban structure and commuting behavior

Much information can be obtained from looking at the pattern of employment location and residential density in hypothetical urban spatial structures (that approximate in size and shape to the largest metropolitan regions of the world) and making assumptions about the commuting preference of their workers. This was the approach taken by Black and Katakos (1987) who considered the matter with completely centralized,
completely decentralized, and poly-centric employment patterns. By assuming that workers are distance minimizers (for the journey to work, subject to the obvious land-use constraints) and distance maximizers, the boundary conditions for the amount of travel, and hence mean trip lengths, can be uniquely determined. The origin-destination patterns of traffic may be determined either from the following linear programming model (classical transportation problem of operations research):

Minimize \[ Z = \sum_i \sum_j T_{ij} c_{ij} \]  
Subject to the land-use origin constraint \[ \sum_j T_{ij} = A_i \] 
Subject to the land-use destination constraint \[ \sum_i T_{ij} = B_j \] 
Non-negative flows are not allowed by \[ T_{ij} \geq 0 \] 

Or, Maximize \[ Z = \sum_i \sum_j C_{ij} T_{ij} \]  
Subject to exactly the same three constraint equations as above

Masuya and his colleagues have greatly advanced our knowledge of travel behavior in such hypothetical urban structures, but has also complemented this research with detailed analysis of journey to work travel in Sapporo, Japan, and in other cities of Hokkaido (see, Masuya et al., 2002, 2003).

4. Employment cluster dynamics in istanbul

Istanbul has a very important place among all the other historical cities in the world, mostly for its key position between Europe and Asia, connecting them through the Bosphorus Strait (Fig. 3). The city has shown rapid growth after the First World War and became the core of the Turkish economy. Such a development, together with the driving forces of spatial dynamics, brought about a poly-centric and mixed urban pattern over an area

Fig. 3. Highway network in the greater metropolitan area of Istanbul.
of more than 150,000 hectares. Two transportation master plan studies (Turkish Republic, Greater Istanbul Municipality, 1988, 1997), which formed the data base for our research, were conducted in 1985 and 1997 on 209 traffic analysis zones. Between the two years, population increased from 5,347,147 to 9,057,747 and employment increased from 1,875,500 to 2,532,211. Istanbul still keeps on growing at an average annual rate of 4.3%, and today’s population of 11 million is expected to reach 16 million by the end of 2030.

4.1. Cluster classification and cluster dynamics

The rank size distribution methodology described in Section 3 was adapted to Istanbul. Logarithmic employment gross density rank size distribution was drawn and clusters, based on 1997, are shown in Fig. 4. Although the previous work (Alpkokin et al., 2005) grouped the zones into three clusters by using only visual inspection of the curve, here, for a more elaborate analysis of cluster dynamics, we worked with four tiers of clusters as defined in Section 3. We adapted the Spearman rank correlation to find the cut off for clustering of 138 zones for 1997 values given by Eq. (7) where \( N \) is the total number of samples; \( x_i \) common rank of all elements in \( i \)th nominal class; \( y_{ij} \) \( i \)th \( Y \) rank of the \( j \)th element; and \( g \) is the number of clusters.

\[
r = 1 - 6 \sum_{i=1}^{g} \sum_{j=1}^{n_i} (x_i - y_{ij})/N(N^2 - 1) \tag{7}
\]

Excluding the zones with zero employment and zones with very small employment that both gave a negative logarithm value, 123 zones for 1985 and 138 zones for 1997 were included into the analysis out of a total of 209 traffic zones. The rank correlation resulted in values of 5.1, 4.1 and 2.8 on the \( y \)-axis as logarithmic scale of employment density. However, we rounded and defined the zones as: cluster 1 logarithmic employment density is larger than 5; cluster 2 between 5 and 4; cluster 3 between 4 and 3; and cluster 4 less than 3.

Table 1 also summarizes some descriptive statistics for employment location dynamics between 1985 and 1997, comparing them very briefly with Chicago and Los Angeles. It is evident that there is a similar pattern of employment location change in each city with the old city loosing its share whereas newly developing agglomerations are gaining shares over the total. For example, Chicago edge city increased the employment stock between 1980 and 1990 that was as much as that of cluster 3 employment gains in Istanbul between 1985 and 1997.

When examining Istanbul in more depth with the proposed cluster analysis, it is evident that the real urban dynamics are occurring outside the cluster 1 zones – all of which are located in the downtown. Istanbul kept developing its traditional CBD center without loosing its primacy and therefore there is almost no change for the first tier of zones. This is also in line with one of the three main strategies of the Istanbul Metropolitan Area Sub-Region Master Plan (Turkish Republic, Greater Istanbul Municipality, 1995), that is, “abandoning the concept of concentric development as the single biggest danger that can destroy the historical identity of
The largest growth was observed for cluster 2 and 3 zones proving an urban form of locally centralised, rather than saturated, development. Again, the Master Plan stresses a growth of the urban macroform in a linear and multi-centered fashion, but with a degree of hierarchical ranking encouraging employment sub-centers, specifically “wing-attraction centers” to control the growth.

Fig. 4 compares rank size distributions for Istanbul between 1985 and 1997 as an illustration of the methods showing the findings given in Fig. 1. When only the Lorenz (Fig. 5) curve was drawn for the two years, as expected, it appears more flat for 1997 since it approaches the diagonal. Although the word “flatness” may mean a more saturated and homogenous distribution, or more sub-centers with rather high densities, for the case of Istanbul with more local peaks, it is difficult to distinguish this only from the Lorenz curve. This emphasizes the importance of applying a rank size distribution analysis. Fig. 6 draws the employment densities for both years as 3D map visualizing the noticeable linear clustering of employment, particularly within the presumed wing attraction points and the new agglomerations around the beltway of the second Bosphorus Bridge.

Table 1
Simple descriptive statistics for cluster dynamics

<table>
<thead>
<tr>
<th>Cluster</th>
<th>1985 employment (share of total)</th>
<th>1997 employment (share of total)</th>
<th>85–97 employment change (share of total change)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CBD</td>
<td>243,300 (13%)</td>
<td>250,000 (9%)</td>
<td>3% (−31%)</td>
</tr>
<tr>
<td>Downtown</td>
<td>651,600 (35%)</td>
<td>658,000 (24%)</td>
<td>1% (−32%)</td>
</tr>
<tr>
<td>Cluster 1</td>
<td>626,200 (33%)</td>
<td>773,400 (28%)</td>
<td>24% (−17%)</td>
</tr>
<tr>
<td>Cluster 2</td>
<td>496,500 (26%)</td>
<td>955,000 (34%)</td>
<td>92% (+30%)</td>
</tr>
<tr>
<td>Cluster 3</td>
<td>450,000 (24%)</td>
<td>766,800 (27%)</td>
<td>70% (+15%)</td>
</tr>
<tr>
<td>Cluster 4</td>
<td>309,000 (16%)</td>
<td>209,100 (10%)</td>
<td>−3% (−35%)</td>
</tr>
</tbody>
</table>

Los Angeles* 1970 employment 1980 employment 70–80 employment growth

| Downtown | 615,000 | 605,000 | −2% |
| Sub-center| 793,000 | 990,000 | +25% |
| Total    | 4,000,000 | 5,300,000 | +33% |

Chicago** Share of total (1980) 80–90 share of total changes

| Old city | 8% | −23% |
| Edge city| 21% | +62% |

* Source: Giuliano and Small (1999).
** Source: McMillen and McDonald (1998).

Istanbul”. The largest growth was observed for cluster 2 and 3 zones proving an urban form of locally centralized, rather than saturated, development. Again, the Master Plan stresses a growth of the urban macroform in a linear and multi-centered fashion, but with a degree of hierarchical ranking encouraging employment sub-centers, specifically “wing-attraction centers” to control the growth.

Fig. 4 compares rank size distributions for Istanbul between 1985 and 1997 as an illustration of the methods showing the findings given in Fig. 1. When only the Lorenz (Fig. 5) curve was drawn for the two years, as expected, it appears more flat for 1997 since it approaches the diagonal. Although the word “flatness” may mean a more saturated and homogenous distribution, or more sub-centers with rather high densities, for the case of Istanbul with more local peaks, it is difficult to distinguish this only from the Lorenz curve. This emphasizes the importance of applying a rank size distribution analysis. Fig. 6 draws the employment densities for both years as 3D map visualizing the noticeable linear clustering of employment, particularly within the presumed wing attraction points and the new agglomerations around the beltway of the second Bosphorus Bridge.

Fig. 5. Lorenz curve drawn for employment (1985 and 1997).
5. Examining transportation in Istanbul

In contrast to many Western cities experiencing growth, commuting times have declined for the journey to work even with employment growth. Over the whole of the region, average morning peak-hour trip times for motorized travel decreased from 53 min in 1985 to 41 min in 1997 – a remarkable outcome given the growth in traffic over that period. Such a 12-min decrease during 12 years is explained by two important factors. First, the construction of the second Bosporus Bridge, with its expressways, improved travel times for both drivers and users of public transportation. Second, the multi-centric growth of the city has put more jobs within reach of suburban residences. The next two sections will further analyze the cluster-specific commuting behaviors and transportation levels of service as outlined by Fig. 1. For this, we have selected 10 zones based on location and representative examples of the clusters to which each was belonging in 1985 and 1997 (Fig. 7). Unlike the literature on American cities, most of which is inclined to give aggregate results for each employment cluster tier, or in other words each type of center, we think this extra illustration provides insights not apparent at the aggregate level.

5.1. Cluster-specific transport level of service

Highway and public transportation accessibility indices were computed separately for the selected 10 zones for both 1985 and 1997 in order to grasp the cluster-specific changes over the time period of interest (Fig. 8).
The highway accessibility was calculated by Eq. (1) for the peak-hour trip time, and the shares of each zone of the total highway accessibility for the 10 chosen zones were computed as percentages in Fig. 8a. Based on the same approach, the public transport accessibility percentages for the 10 zones were computed based on the formulation given in Section 3.3 by Eq. (4) (Fig. 8b). However, the given formulation does not incorporate the transfer waiting time within the public transportation network – that is, between buses, minibuses, ferries and railway in the case of Istanbul where the mean number of transfers on public transportation is found from surveys to be approximately 1.5. The public transportation accessibility formulation was modified as below by adding the summation of transfer waiting time $\bar{X}$, where $m$ is the number of transfers for the undertaken trip between $i$ and $j$ (Eq. (8)).

$$A''_{ij} = L_{ij}\exp^{-\beta_{ij}+X_{ij}+\sum_{k=1}^{m}\bar{X}_{ik}}$$  \hspace{1cm} (8)

Such models require access to land-use and transportation models calibrated for each city. The traffic assignment sub-module of TRANPLAN was employed in order to compute the transfer waiting time results of the public transportation system in Istanbul. As O-D surveys did capture the details about public transportation trips about where, and to and from which mode, the transfer took place, in Istanbul this analysis was feasible to undertake.

The highest highway accessibility is found in the downtown and in the high density clusters around the city center. However, noticeable shifts in job accessibilities in the outer rings of the city result from the construction of the motorway (Transit European Motorway) and the second highway Bosphorus Bridge. Variations between the public transportation and highway accessibility map reveals the necessity for a separate consideration of accessibility. The highest public transportation accessibility share-gains was for zone Esenler_2.
between 1985 and 1997 because the LRT system started operating between these years. Also, the increases in the far eastern and western sides of the metropolis were the results of the bus service improvements with the growth of these zones.

5.2. Cluster-specific commuting behavior

The spatial extent of trips attracted to each major employment zone in 1997 was examined using the employment location-specific preference function and the trip length frequency distribution of those commuter journeys to that employment zone. Employment-specific preference functions are shown in Fig. 9.

The zones labeled in this figure are zones Eminonu_5 and Kadikoy_2 in cluster 1; zones Kcekmece_4, Pendik_1 and Beyoglu_6 in cluster 2; zones Kadikoy_6, Kagithane_1 and Esenler_2 in cluster 3; and zones

Fig. 8. Accessibility shares for each zone as of the total of the shown ten zones.
Kcekmece_7 and Sultanbeyli in cluster 4. Peak-hour trip time between all other zones for the ranking of residential opportunities around each employment zone was used. The noticeable feature of Fig. 9 is the different patterns in the zonal preference functions, as highlighted by the three black oval lines. Employment zones Kcekmece_7 and Pendik_1 are outer suburbs on the European and Asian sides, respectively, and capture a very high proportion of workers from very nearby residences (from 70% to 80% of all commuter trips) – indicating a minimizing approach to the journey to work by these commuters. On the other hand, for zones Eminonu_5 and Kadikoy_2 (cluster 1) only from 5% to 20% come from nearby residential opportunities, and these curves, extreme to the right of the other two groupings, depict a metropolitan-wide labor market. In between, zone Kadikoy_6 (cluster 3) is representative of zones capturing both local (about half), and wider metropolitan commuters.

Cumulative trip length frequency distributions in the morning peak, plotted for the motorized trips attracted to the selected zones for 1985 and 1997, also strengthen the above findings of the preference functions (Fig. 10). When examining the two time periods, the trip length frequency distributions for the old CBD zone were found to have a more flat distribution and a rather more stable shape during the 12 years. However, the two sub-centers as wing attraction nodes attract a considerable portion of their trips from close to each center, although they did attract trips from greater distances too in 1997 (Pendik_1 and Kcekmece_4), bringing about the noticeable fact that as the zone grows to accommodate more employment opportunities, the shorter trips attracted gained a higher share. For example, for journeys to zone Kcekmece_4, a substantial increase was observed for the trips between 45 and 49 min from 7% to around 37%. Kadikoy_6 – a newly emerging sub-center close to the downtown of the Asian side – attracted very short trips due to two important reasons. First, it is very close to the high-density residential locations, and, second, an expressway passes through the zone, also providing a wide public transportation service by very frequent bus and minibus networks.

Table 2 compares Istanbul with San Francisco and Los Angeles for commuting patterns by means of modal share and one-way average commuting time attracted by the employment zone, or type of center. Unlike the two American cities, the average commuting time decreased in all the zones due to highway improvements, especially the second bridge and its beltways. There was a very slight increase in the average speed coded

---

6 The authors conclude the severe changes of the percentage of trips for the subsequent time range is not the real case because of bias in answers to questions. For example somebody leaving home for work at, for example, 7:19 a.m. would probably record this as 7:20 a.m. But this does not alter the interpretations derived from the zone-specific TLD curves.
in the transport package from 1985 to 1997. The average network speed, as coded in the software package for the buses and minibuses increased from 21 km/h in 1985 to 27 km/h in 1997. Here, we were not able to give the distances traveled since the O-D surveys only included trip time, not distance (the results of either equilibrium highway assignment, or shortest path, could be used to calculate the distances but the results were not presented here). The average trip time increases were higher for the eastern and western zones promoted as wing attraction at an average of 25%, as explained by the result of network improvements and a shift to the catchments of the work-force from shorter to longer distances as they grow in employment size. The highest increase was observed for Kagithane_1 as it is nearby a rapidly growing zone at the intersection of the second bridge beltway.

When considering the zone-specific modal split attracted to the zone in question, the results are basically similar to the other empirical findings. However cluster-specific mode share variations are much more moderate in the case of Istanbul than in San Francisco (Public transportation shares in San Francisco: downtown 28%; and suburban center 2%). The public transportation share is the highest for the old CBD of Istanbul with 58% (eminonu_5). For the suburban clusters, there are rather mixed results. There is a low public transportation share with 39% for the western wing attraction zones (Kcekmece_4 and Kcekmece_7) but higher shares for other western suburb zones with 47% and 48% for zones Kadikoy_6 and Pendik_1, respectively. Such a variation is mostly due to the income distribution – that is, there are higher income groups on the west side than on the eastern side of Istanbul. The results of the public transportation mode shares that do not much favor the Istanbul CBD can be attributed to the fact that the city is served by a rather uniform highway network, and hence public transportation, because buses and minibuses together form the main body of the public transportation network.\footnote{28.6\% of the total trips are made by car and 65.2\% are by public and private service buses or minibuses. There was not a noticeable modal share change for 12 years despite that the car ownership almost doubled and reached 98 car/1000 inhabitants in 1997.} In other words, a more uniform public transportation network attracted a good number of suburban workers, and hence a more uniform modal share for Istanbul.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig10.png}
\caption{Journey to work trip length distribution for four zones, 1985 and 1997.}
\end{figure}
6. Conclusions

Market forces or planned intervention in the large metropolitan areas of the developing world are transforming the urban spatial structure away from a predominantly mono-centric urban form to a more diffuse, or a poly-centric employment structure, yet the dynamics of this change has not been studied. This is in marked contrast to the literature on this topic for North American cities. We have developed a suitable framework for the analysis of rapidly growing cities in the developing world that recognizes data limitations. This analytical methodology emphasizes the objective of different kinds of studies, suitable analytical techniques available, and what the output from such analysis might tell the planners and decision makers (Fig. 1).

The simple analytical methods proposed, allow investigations into the identification of the major employment clusters being formed, into a better understanding of the dynamics of employment change in the region, into the accessibility of such clusters provided by the highway and public transportation networks, and into the commuting behavior of workers in each cluster’s labor market from a perspective of destination specific preference functions, trip length distributions and transportation mode shares (Section 3). The methods described are illustrated with particular reference to employment cluster dynamics in Istanbul, Turkey, from 1985 to 1997 – a region that grew its employment base in 1985 of 1.9 million jobs to 2.5 million in 1997.

In the case of Istanbul, we have shown there are four distinct types of employment cluster located in the area of more than 150,000 hectares. We discuss their changing market share of regional jobs, and compare the changes to those found in San Francisco, Los Angeles and Chicago, and illustrate these changes with the aid of Lorenz and rank size distribution curves drawn for 1985 and 1995. Whereas changes in accessibility, trip length frequency distributions and transportation mode shares have been studied by numerous researchers, the application of Stouffer’s theory of intervening opportunities to employment zone preference functions to identify characteristics of spatial labor markets we believe is a novel, complementary approach. Again, these techniques of analysis have been illustrated by selecting 10 representative employment clusters in Istanbul.

The application of the framework to Istanbul has demonstrated its robustness given the urban transportation study data likely to be available in many large cities of the developing world. In fact, when we presented

<table>
<thead>
<tr>
<th>Cluster examined</th>
<th>Year</th>
<th>Public transport share (1997)</th>
<th>One way av. peak time (min) 1985/1997 (change %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kekecme_4</td>
<td>4/2</td>
<td>39</td>
<td>72/55 (–24)</td>
</tr>
<tr>
<td>Kekecme_7</td>
<td>4/4</td>
<td>39</td>
<td>56/45 (–19)</td>
</tr>
<tr>
<td>Esenler_2</td>
<td>4/3</td>
<td>43</td>
<td>52/46 (–11)</td>
</tr>
<tr>
<td>Eminonu_5</td>
<td>1/1</td>
<td>58</td>
<td>55/49 (–10)</td>
</tr>
<tr>
<td>Kagithane_1</td>
<td>4/3</td>
<td>51</td>
<td>79/53 (–33)</td>
</tr>
<tr>
<td>Beyoglu_6</td>
<td>3/2</td>
<td>53</td>
<td>55/49 (–10)</td>
</tr>
<tr>
<td>Kadikoy_2</td>
<td>2/1</td>
<td>44</td>
<td>50/45 (–10)</td>
</tr>
<tr>
<td>Kadikoy_6</td>
<td>4/3</td>
<td>47</td>
<td>46/37 (–20)</td>
</tr>
<tr>
<td>Pendik_1</td>
<td>4/2</td>
<td>48</td>
<td>69/49 (–29)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Metropolitan area</th>
<th>One way commute time (min)</th>
<th>One way commute distance (miles) 1980</th>
</tr>
</thead>
<tbody>
<tr>
<td>Istanbul examined</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kekecme_4</td>
<td>39</td>
<td></td>
</tr>
<tr>
<td>Kekecme_7</td>
<td>39</td>
<td></td>
</tr>
<tr>
<td>Esenler_2</td>
<td>43</td>
<td></td>
</tr>
<tr>
<td>Eminonu_5</td>
<td>58</td>
<td></td>
</tr>
<tr>
<td>Kagithane_1</td>
<td>51</td>
<td></td>
</tr>
<tr>
<td>Beyoglu_6</td>
<td>53</td>
<td></td>
</tr>
<tr>
<td>Kadikoy_2</td>
<td>44</td>
<td></td>
</tr>
<tr>
<td>Kadikoy_6</td>
<td>47</td>
<td></td>
</tr>
<tr>
<td>Pendik_1</td>
<td>48</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Metropolitan area</th>
<th>Public transit share (1990)</th>
<th>Av. commute time (min) 1980/90 (change %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Istanbul examined</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kekecme_4</td>
<td>39</td>
<td></td>
</tr>
<tr>
<td>Kekecme_7</td>
<td>39</td>
<td></td>
</tr>
<tr>
<td>Esenler_2</td>
<td>43</td>
<td></td>
</tr>
<tr>
<td>Eminonu_5</td>
<td>58</td>
<td></td>
</tr>
<tr>
<td>Kagithane_1</td>
<td>51</td>
<td></td>
</tr>
<tr>
<td>Beyoglu_6</td>
<td>53</td>
<td></td>
</tr>
<tr>
<td>Kadikoy_2</td>
<td>44</td>
<td></td>
</tr>
<tr>
<td>Kadikoy_6</td>
<td>47</td>
<td></td>
</tr>
<tr>
<td>Pendik_1</td>
<td>48</td>
<td></td>
</tr>
</tbody>
</table>

- Due to the loss of data, the 1985 year zone-specific modal shares could not be given.
- Source: Giuliano and Small (1999).

<table>
<thead>
<tr>
<th>Cluster examined</th>
<th>Year</th>
<th>Public transport share (1997)</th>
<th>One way av. peak time (min) 1985/1997 (change %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kekecme_4</td>
<td>4/2</td>
<td>39</td>
<td>72/55 (–24)</td>
</tr>
<tr>
<td>Kekecme_7</td>
<td>4/4</td>
<td>39</td>
<td>56/45 (–19)</td>
</tr>
<tr>
<td>Esenler_2</td>
<td>4/3</td>
<td>43</td>
<td>52/46 (–11)</td>
</tr>
<tr>
<td>Eminonu_5</td>
<td>1/1</td>
<td>58</td>
<td>55/49 (–10)</td>
</tr>
<tr>
<td>Kagithane_1</td>
<td>4/3</td>
<td>51</td>
<td>79/53 (–33)</td>
</tr>
<tr>
<td>Beyoglu_6</td>
<td>3/2</td>
<td>53</td>
<td>55/49 (–10)</td>
</tr>
<tr>
<td>Kadikoy_2</td>
<td>2/1</td>
<td>44</td>
<td>50/45 (–10)</td>
</tr>
<tr>
<td>Kadikoy_6</td>
<td>4/3</td>
<td>47</td>
<td>46/37 (–20)</td>
</tr>
<tr>
<td>Pendik_1</td>
<td>4/2</td>
<td>48</td>
<td>69/49 (–29)</td>
</tr>
</tbody>
</table>
an earlier version of the framework at the 9th Conference of Computers in Urban Planning and Urban Management (CUPUM) held at University College London in June, 2005, we were encouraged by participants joining the session to look at the same issues in Asian, African and South American metropolitan regions. The collective experience of the authors does not extend to the African and South American continents, but we have initiated and completed an international comparison of cities drawn from Asia and Australia where, together with collaborating colleagues, we do have the necessary extensive professional planning experience. One particular focus will be the planning studies and planning policies on urban spatial re-structuring and employment decentralization and the degree to which such policies have been successfully implemented based on the techniques proposed in this paper. Given the extensive literature on North American cities, such as San Francisco and Los Angeles, we hope to persuade collaborators to augment their research by including some additional analyzes.

Acknowledgements

The authors thank the Turkish Republic, Greater Istanbul Municipality; the Department of Transportation, The Technical University of Istanbul (I.T.U.), and the companies of STFA, Planofis and MNL Insaat for providing the data. They are especially grateful to Prof. Dr. Haluk Gercek (I.T.U.) as the head of the project “Istanbul Transportation Master Plan, 1997, I.T.U.” and a key advisor to the government, for his support to this research. After submitting this paper for review we successfully obtained funding from the Eastern Asia Society for Transportation Studies (EASTS).

References


Turkish Republic, Greater Istanbul Municipality, 1995. Istanbul Metropolitan Area Sub-Region Master Plan by 1/50.000 Scale. Planning and Zoning Control and Construction General Department, City Planning Directorate, Istanbul, Turkey.

