A Tale of Two Cities: Density Analysis of CBD on Two Midsize Urban Areas in Northeastern Italy*

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Abstract. The paper is focused on the observation of urban form and functions and is aimed at identifying a method for the cartographic definition and representation of CBD (Central Business District). The analysis is developed to explore the formation of centers of different order in the urban environment, starting from the locations of a selected set of human activities located in urban areas. An index of concentration of central activities is presented to allow the visualization of the functional urban environment by means of a density surface, therefore highlighting areas where central activities and functions concentrate. The paper is based on analyses related to spatial statistics in a GIS environment. We provide a short review of the literature on CBD research, briefly describe the kernel density estimation method, and propose how this can be used in order to test the index of concentration of activities and therefore delineating CBD, presenting evidence from two urban areas in Northeastern Italy (Trieste and Udine).

Keywords: Central Business District, Kernel Density Estimation, GIS, Nearest Neighbor Analysis, Trieste, Udine.

1 Urban Analysis and the Definition of Centers

The Central Business District as a geographical concept is to-date quite settled and has been examined through the years by the researchers in many different urban contexts around the world. The activities carried on in the CBD have changed during the years, as well as the same location of many Business Districts that, in time, have often abandoned a central location in favor of more decentrated ones where central constraints - high rents, competition for land use, lack of floor space suitable for large businesses, traffic congestion - limit to-date financial and directional activities locating in the 'true' geographical centre of an urban area.

However, centers maintain their importance in shaping cities and orientating their functions and roles. Despite some activities move out from the centers, many ones remain there, therefore characterizing central urban landscape and functions.

Studies intended to highlight functional areas within urban areas have drawn the attention of geographers and scholars from other disciplines, as urban ecologists,

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sociologists and economists. Burgess, Hoyt (1939) and Harris and Ullman (1945) are among the first ones to be interested by the urban phenomenon, particularly in terms of the definition of the urban shape and highlighting functional areas within cities, as the central business district (CBD) or other areas characterized by different kinds of human activities.

Central places' theory has been applied to the 'internal' urban environment, highlighting those human activities relevant for defining urban hierarchies and for organizing the urban space (Scaramellini 1993). Several authors have hypothesized the existence of density functions decreasing from the central areas of the city in terms of urban land use and its value (Knos 1962; Haggett 2001), the supply of transport infrastructures (Alonso 1960) and the population distribution (Clarke, as reported in Yeates and Gardner 1976).

Different patterns of development have been considered. First urban models were simpler and based on a circular and concentric structure of urban areas, followed by sector models and radials ones from a central location in the central city. In recent years the debate concerned the monocentric versus polycentric nature of cities (Hoch and Waddel 1993; Waddel, Berry and Hoch 1993), where the existence of a central urban nucleus is discussed and compared to patterns of development not so homogeneous and uniform but where several centers coexist and whose origin can be derived from the presence of activities different from those that are typically 'central' ones and from the individuals' behavior in terms of residential choices. Several researches in the first years of this century are focused on these behaviors on residential choices, following the studies on urban polycentrism. The time factor is dominant in these studies and considered to explain the patterns of mobility and accessibility, not only towards the central areas of a city but also, and particularly, to the places of individual interests that are not necessarily located in central areas (Weber and Khan 2002). Physical distance is therefore put in second order, mainly considering more complex and 'non-Euclidean' elements as the time component of accessibility and the geographical or time distance is considered mainly over a network, and therefore characterized by non homogeneity and anisotropy, and therefore creating directional spaces for the individuals (Miller 1994, Batty 2005, Borruso 2008).

In order to analyze an urban environment not so homogeneous and uniform but characterized by the presence of different centers, new and more refined methods are required to study the urban development and its functions, among these the spatial statistics (Cuthbert and Anderson 2002), GIS (Batty and Longley 1994) and urban modeling.

The combined experiences from these research agendas allow the observation of urban space and the deepening of the urban dynamics. New analytical instruments together with the wide availability of geographical data recall the need of new methods and instruments for extracting new information. Among these we can remind the use of surfaces to analyze and represent urban phenomena, as the density of population or human activities more in general. Although these are not really new methods and concepts (Matheron 1963; Atkinson 2005) and now consolidated in the analysis of urban functions, their application is to-date possible and interesting thanks to the availability of data and analytical tools.

The efficiency of such methods is developed together with the simple structure of the data used, represented by sets of points in space, characterized by the position of

human activities in space, these representing the starting elements to obtain continuous density functions for estimating the spatial distribution of a phenomenon (Gatrell 1995), to define urban centres (Thurstain - Goodwin and Unwin 2000), other than being particularly effective from the cartographical point of view.

2 Indexes of Urban Centrality

2.1 The CBD

The Central Business District (CBD), following studies carried out in urban geography and sociology during the first half of the Twentieth Century is located in the central part of a city, together with particular activities, as banks, offices, hotels, cinemas and theatres (Haggett 2000). The CBD areas are generally characterized by tall buildings, high density road traffic and high population density in daytime. In the CBD the land values are higher than in the rest of the urban area, generally following a decreasing function starting from the city centre, where the highest value is reached, towards the peripheral areas. From a cartographical point of view urban geographers visualize such function by means of a three-dimensional surface determined by the different land values over the urban space. Such land value function is generally decreasing as the distance from the city centre increases and can present variations and lower intensity peaks located at minor settlements and at the intersection of major arterial roads. The land value surface will represent the different accessibilities of the different parts of the city and show the locations where a higher competition for space between human activities take place.

2.2 Towards the Delimitation of the CBD

Scholars involved with urban studies have tried to find methods do delimitate the extension of the CBD and to represent it cartographically. In such sense both qualitative and quantitative indexes are implemented, with the former being mainly based on individual choices and observation and the latter mainly used in quantitative analysis.

It is possible to recall some of the most used indexes in Anglo-Saxon literature, as reported by Murphy and Vance (1954b) and re-examined in several urban geography studies (Table 1). Most of such indexes are referred to the concentration of central activities that can be computed starting from other indexes of intensity of CBD, not only referred to the surfaces occupied by central activities, but also from the height of buildings in central areas, as well as the intensity of central activities.

The concentration of the activities defined as ‘central’ is generally quite high in central areas and coupled with high land values, and the land value function generally appears as decreasing when moving out from a city centre with minor peaks at major road intersections or at minor settlements. Such concentration was used to delineate the shape and extensions of a CBD (Murphy and Vance, 1954a).

Other authors stress the importance of the comparison between day and night populations (Carol, 1960), underlining the substantial lack of resident population in CBD areas where people are present only in working times during the day with some

Table 1. A classification of Land Uses in the CBD (Murphy and Vance, 1954b)

A – present and apparently typical	Restaurants; Women's clothing; Men's clothing; Furniture; Hardware and appliances; Department stores; 5 and 10 stores; Drug stores; Jewellery and gifts; Amusement establishments; Banks Insurance and Real estate; Personal service; Clothing service; General offices; Commercial parking; Hotels and other transient lodging
B - Rare enough to be absent or essentially so from one or more of the CBDs	Supermarkets; Automobile sales; Service stations; Accessory, tire, and battery sales; Newspaper publishing; Headquarter offices; Railroad station; Bus station; Residences; Industrial; Wholesale
C - Occupying substantial space in all CBDs but not typically central business land use	Public land and buildings; Organizational and chartable institutions; Vacant building or lot space

Activities collected in Murphy and Vance' field notes research (1954a and 1954b).

exceptions for people in search of leisure and free time activities at night. Such characteristics have changed during the years, making it necessary to calibrate analytical instruments and to focus also on other elements of observation.

With reference to the research carried out in Italy in urban studies, this is not the place to recall the overall path marked by scholars through the years, but just to recall how from the end of Sixties they developed and went in depth with studies on cities and observed the dynamics over the different national contexts, reminding the complete analysis performed by Scaramellini (1993). However it is important to recall, with particular reference to the local cases examined here, the works by Bonetti (1967; 1975) on central places and urban functions; by Battisti (1980) on metropolitan functions and by Corna Pellegrini e Pagnini (1975) on retail activities[1].

The attention on CBD has been focused on different kinds of activities, as tertiary activities (Bonetti, 1967), although this term was not used, but recalling particularly central activities, as already implicit in Berry (1967). The CBD represents the central place having the highest rank, the place where the most important activities of a city are located, not only as the more specialized retail activities, but also considering the administrative and professional ones.

A metropolitan city (Bonetti 1975) represents the specialized nucleus of a metropolitan area and constitutes itself a region. With that in mind different centres and their catchment areas for different functions or combinations of functions can be highlighted within a metropolis. CBD services are available not only for the city but also for its tributary area, definable as *hinterland* or *umland*.

The main subject of studies on CBD however are not only services but, as Scaramellini points out (1993b) there is a difference between the 'tertiary sector' and a central function. The former is referred to a historical-morphological distribution of economical activities, while the latter is referred to activities classified according to their capacity of action over space.

[1] Among the Italian local cases it is important to remind the analysis on CBD carried out by De Matteis (1966) on the urban area of Turin.

Central functions are not only the tertiary ones but also the secondary one dedicated to the local market. Industrial production can be central as urban location but also to serve a surrounding area with the products realized (Scaramellini 1993b). Functions become therefore central from their capacity of organizing spaces according to the needs originating from urban people.

The question to-date is what are the activities and categories to be considered for determining the CBD. For retail activities, Bonetti highlights the importance of those for individuals, as selling of goods and provision of services, not only retail. The more specialized activities or those providing the highest quality or variety of goods will be based in the CBD. These will be high value retail activities, as fashion retail, jewelleries, financial activities as banks and insurance companies, professional bodies – lawyers, architects, accountants, public bodies.

Among the 'classical' characteristics of CBD studied particularly in North-American cities, it must be reminded how the residential density is quite low in central areas, with a crater-like shape in some cities. Such shape is also confirmed for some urban areas in Italy (Borruso 2003), leaving room to interpret this as a higher diurnal population density if compared to the residential one. Other processes are ongoing, as the *gentrification*, or the progressive infill and redevelopment of central urban soils thanks to particular and 'creative' activities and the related population (Morrill 2006), with an increased use of such areas not only for working daily activities but also for those related to free time and leisure, spread over a wider timeframe during the day and covering also evening and night times. Also, in recent years urban tourism has increased, thanks also to the dynamics of urban centre redevelopments and re-definition of central functions of the city.

2.3 CBD and New Locations

The choice of central activities to-date should consider the changes intervened through years in urban structure and settlements. Many activities have abandoned the urban areas or at least their more central parts. This is the case of retail after the development of wholesale retail and the settlement of huge retail areas outside the city centres and along major communication routes (*shopping centres* and *malls*), moving a certain kind of shopping and retail out of the centres, spoiling them of the exclusivity of retail supply[2], although many cities are experimenting a renewed attention by retail activities towards a central location.

Also CBDs in many urban areas tend to move outside the city centres, mainly moving to more peripheral areas that are characterised by lower rents but also a suitable level of accessibility by means of private transport means and public ones, forming functional quarters inhabited during the day but deserted at night, these areas consisting mainly on directional buildings hosting banks, financial and insurance companies.

A similar trend can also be noticed in the case of headquarters of big companies that tend to move outside central areas, thus creating 'peripheral' CBDs, therefore not linked to the urban 'geographical barycentre'. Examples in different contexts can be

[2] See Bullado and Buzzetti (2001) and Bullado (2002) for a complete analysis of the characters of wholesale retail in Italy.

reminded, as the new business district at Canary Wharf in London (UK), born after the urban redevelopment of the Docklands area, outside the traditional City of London square mile, as well as the Lujiazui CBD quarter in Shangai (Jones Lang LaSalle 2007). Examples closer to the study area being analysed can be reminded, as directional centres of insurance (Lloyd Adriatico - Allianz Group) and shipping companies (Lloyd Triestino, now Evergreen) moved out from the true barycentre of the city to the industrial and port areas. In the case of Udine, a new area of development of offices, financial services and retail has developed north from the city also in this case out of the *core* itself.

3 Density Analysis of CBD

3.1 The Method

The Kernel Density Estimation (KDE) used allows transforming point events in space in a continuous density function over the study region considered, thus allowing a visualization of the phenomenon by means of a three-dimensional surface, not limited to the single point event, but representing the variation of density of point events across the study region. The method allows modelling point data over a grid structure that covers the entire study region. Each grid cell is attributed a density value according to the events' distribution. KDE is generally used for applications regarding generally earth science, biology and epidemiology, but recently a wealth of applications to social science have flourished, as to examine the density and distribution of population or the clustering of human activities over space. The kernel consists of a family of 'moving three dimensional functions that weight events within its sphere of influence according to their distance from the point at which the intensity is being estimated (Gatrell et al 1996; Gatrell 1994). The general form of a kernel estimator is:

$$\hat{\lambda}(s) = \sum_{i=1}^{n} \frac{1}{\tau^2} k\left(\frac{s - s_i}{\tau}\right) \tag{1}$$

where $\hat{\lambda}(s)$ is the estimate of the density of the spatial point pattern measured at location s, s_i the observed i^{th} event, $k(\ )$ represents the kernel weighting function and τ is the bandwidth. τ represents a circumference's radius, centred in location s, within which events s_i are counted and will contribute to the density function (Gatrell, 1994). The bandwidth, or searching radius, τ represents the only arbitrary variable which defines the extent of the searching function. Too low values of τ produce a too 'spiky' representation of local peaks or, on the contrary, excessively wide bandwidths can cause a too high dilution and homogenization of the observed phenomenon.

The procedure considers using a fine grid over the study region and performing a routine that calculates the distance between each of the reference cells and the event's locations, evaluates the kernel function for each measured distance and sums the results for each reference cell (Levine 2004).

The result obtained consists on an estimate - for each cell in the study region - of the density of events observed within an area defined by the bandwidth, or searching radius, weighted according to the distance of the events from the same cell's centroid.

The cells covering the study region therefore present density values that can be expressed and represented by means of a density surface, which approximates a continuum in the space, presenting 'peaks and valleys' according to the different patterns draw by the distribution of events[3].

3.2 The Study Area

The research has been carried on considering two mid-size cities, Trieste and Udine, in North-eastern Italy, in the Friuli Venezia Giulia Region, at the Italy-Slovenia state border. The two cities represent the two 'souls' of the region and present different characteristics in terms of their locations, roles and economic features and performances.

According to a simplified representation of 'two regions' within one administrative region we can therefore observe the setting of a model based on Trieste and one on Udine as representative of the Friuli area (Figure 1).

Trieste, the Region capital, presents as a province a limited surface of 211 km^2 counting 6 municipalities, making it the smallest Italian province, where however live 236,000 people – 86.8% in the Municipality of Trieste (84.7 km^2), characterizing it as the third province - after much bigger cities as Milan and Naples - in terms of high population density. The population is decreasing due to the very high average age of people, contrasted by an increasing demographic rate particularly from the beginning of the XXI century.

The city is living a decline following a lose of the logistic role as a port and a market for former Yugoslavian consumers, mainly based on a privileged position on the 'iron curtain', suffering as well from the transformations occurred in the European area during the last decade. Trieste dimensions were in fact related to a wider transnational hinterland, both in terms of its port and services - bank, insurance and shipping companies just to name a few. The city is also competing with the neighboring city of Udine for the setting of regional activities and functions, as well as with the port of Capodistria - Koper (Slovenia) in terms of traffic and port functions.

The economic structure is characterized by a production mainly based on services - services counts for the 70.8% of the regional added value: figures raise to 84.6% of provincial GDP, that makes of Trieste the second Italian province in terms of the weight services has on added value creation, mainly addressed to the local community as retail and buildings, together with big players with a solid structure mainly in the insurance, bank and shipping sectors, as well as some big players in heavy industry, while intermediate firms and manufacturing are mainly lacking.

The retail sector is structurally suffering a bigger dimension that the local demand is not able to absorb. Strong elements in terms of future opportunities of development are based on a relevant presence of scientific and research structures, as well as a strategic position to the enlarging market of Eastern Europe.

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[3] See Thurstain-Goodwin e Unwin (2000) for an application of KDE to the analysis of urban centers and on the definition of 'urban centrality' indexes to define statistical units for urban areas. Other applications to city centers for recreational activities in Italian areas are reported by Boffi (2004), while Borruso (2003) examined the population distribution and density, as well as the decreasing density of road transport infrastructure when moving out from the city centre.

Fig. 1. The study area. Trieste and Udine in the Friuli Venezia Giulia Region.

The province of Udine presents a wider surface (4,893.07 km^2) and number of municipalities (137) with 535,992 inhabitants. The Municipality of Udine presents a surface of 56.87 km^2 and counts over 95,000 inhabitants.

If Trieste set on year 1989 - fall of the Iron Curtain - the start of a different declining economic period, Udine can dates back to 1976 - the year of the big earthquake - the start of a process of economic renewal, changing its role from that of a poor area characterized by outbound migrations to a new one of spread, localized and self-generated industrialization, based on small and medium-size enterprises, therefore extending the phenomenon of the industrial districts eastwards from the Veneto area.

Although the industrial sector is quite dynamic and has grown significantly during the last few years, it still presents some weaknesses, mainly concentrated on a general lack in terms of advances services to firms, as well as delays in the realization of connecting transport infrastructures.

Udine also presents important figures in the services - still the one that shows an increase in terms of active firms - and particularly in the retail sector. This latter however experimented a decrease in the number of active firms, although more limited than in the neighboring Trieste.

3.3 The Choice of Data

In order to test the method and to highlight the areas where a higher concentration of urban activities takes place, different categories of activities were chosen, these being among the most suitable of being located in central locations. Categories were

selected among those available in the Yellow Pages service and we tried in particular to follow previous researches on central functions (i.e., Murphy & Vance 1954), therefore focusing on activities as retail, mainly in terms of high quality one, professional bodies, public offices, financial and business services, real estate, leisure activities, arts and culture[4].

Table 2. Urban central activities and their categories in the Municipalities of Trieste and Udine

Category		Sub-category		Total N. of activities	
Order	Description	Description	N. of subcategories	Trieste	Udine
1	Clothing	Clothing (classic; sport; women & man)	4	141	133
2	Arts & culture	Art galleries; auction, theaters, cinemas, museums	5	41	37
3	Banks and Insurance companies	Banks, insurance companies	2	259	194
4	Retail	Commercial agencies, fashion, antiques, jewelers,	6	186	27
5	Professionals	Architects, craftsmen, lawyers, solicitors, notaries, surveyors, designers, consultants on road damages, industry, accountants, commercial and financial consultants, certifiers, chartered surveyors.	19	747	778
6	Services to firms	Translators, interpreters, events management, industrial and technical services, Internet services, Internet web design, marketing, import-export	7	196	58
7	Real estate services	Real estate agencies	1	188	110
8	Free time (Leisure)	Hotels, bars & cafe, B&B, pubs, restaurants, agritourism, pizza house	8	568	269
9	Public buildings / activities	Embassies, Consulate, Local bodies, Public Associations	4	68	53
	Total		56	2,394	1,685

Source: elaboration from Yellow Pages (http://www.paginegialle.it), accessed December 2007 (Trieste); elaboration from Yellow Pages data via Google Earth, accessed June 2008 (Udine).

The main categories considered are also organized in disaggregated sub-categories. This will be particularly important in future research as both qualitative and quantitative weights for the different sub-categories could be assigned before the overall analysis of the spatial index in order to explore different shapes of the CBD itself.

[4] See Bertazzon and Lando (2003) for a recent analysis on high rank service activities in urban and tourist systems, based on Yellow Pages (SEAT - Pagine gialle) aggregated data.

After extracting data from Yellow Pages the activities were georeferenced, geocoding addresses to cartographic street numbers supplied by the municipality of Trieste. It was therefore possible to produce a scatterplot of 'central' activities using GIS software and explore their distribution within the territories of the municipalities of Trieste and Udine.

3.3.1 Trieste

Table 2 presents the activities considered in the Trieste area, grouped by categories and sub-categories. The total amount of activities counts for 2,394 for the Municipality of Trieste, grouped in nine (9) main categories and 56 sub-categories. From the analysis of Table 3, it can be noticed that the first 10 sub-categories cover more than 50% of the total, these corresponding to 1,301 entries. Activities related to food supply, as restaurants and bars among the others, are the most numerous ones. However, high values can be observed also in the overall number of real estate agencies, banks and insurance companies, lawyers, among the professionals, and jewelers in the retail sector.

Figure 2 (right) shows the spatial distribution of the 2,394 activities in the Municipality of Trieste, together with the city road network.

The simple observation of the locations of central activities allows already to notice their concentration in a 'central' area of the city of Trieste, together with a certain correspondence of the more peripheral activities and the main road axes. As De Matteis reports (1991), this is a kind of 'elementary geography', only apparently represented by a simple collection of addresses, that present a more general message concerning the configuration of the geographical space where we live. This scatterplot is however not enough for allowing a more in depth observation of the observed phenomenon, also considering that in many cases a same address point, and therefore a single point element on a map, can be related to several activities, located in different floors spaces in a same building. Different professional activities in higher floors can share the same building with retail activities or public offices.

Table 3. First ten sub-categories of central activities in the Municipality of Trieste

	Category	Sub-category	Number of events	%	Cumulative %
1	Leisure	Bar & cafe	189	7.88	7.88
2	Real estate services	Real estate agencies	188	7.83	15.71
3	Professionals	lawyers	169	7.04	22.75
4	Financial activities	Banks	163	6.79	29.54
5	Retail	Jewelers	112	4.67	34.21
6	Leisure	Restaurants	108	4.50	38.71
7	Financial activities	Insurance companies	96	4.00	42.71
8	Professionals	Surveyors	94	3.92	46.63
9	Services to firms	Import – Export	91	3.79	50.42
10	Leisure	Restaurants	91	3.79	54.21

Source: our elaboration from Yellow Pages data (http://www.paginegialle.it), accessed December 2007.

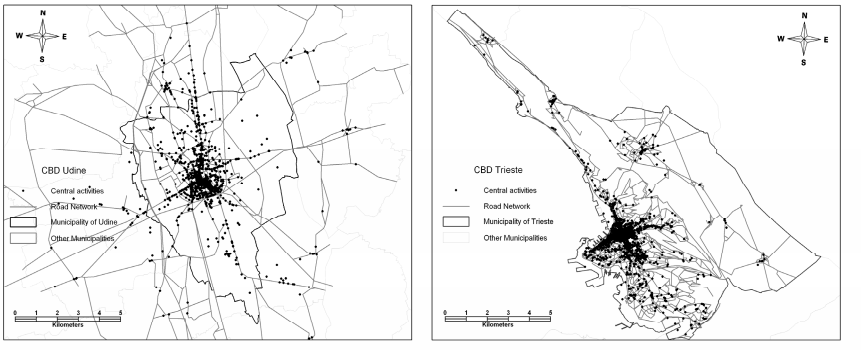

Fig. 2. Central activities and their spatial distribution in the Municipalities of Udine (left) and Trieste (right)

3.3.2 Udine

A similar dataset has been built with reference to the urban area of Udine. Differently from the Trieste case, the activities extracted from Yellow Pages were georeferenced at street number address level by means of Google Earth and converted in GIS formats to be loaded in as a geographical database (Figure 2 left). The 'elementary geography' of activities here refers to an area slightly higher than that enclosed within the borders of the municipality of Udine. The city of Udine in fact developed during the years following the orientation of some major road axis without encountering particular morphological obstacles and therefore spread other the original boundaries. For the activities used in the analysis the area is therefore slightly wider than the municipal boundary. Professionals, with lawyers and architects, as well as clothing, leisure activities as bars and real estate agencies lead the activities located in the municipality of Udine, flanked by banks and insurance companies.

4 Elaborations and Results

4.1 Trieste and Its CBD

Data obtained from the grouping of Yellow Pages activities were processed using Kernel Density Estimations. A fine 20m grid has been overlaid on the study region of the Municipality of Trieste. The 20m cell represents the minimal sampling unit for the density analysis. The kernel function chosen is a quartic one with a 400m bandwidth[5]. Such distance was chosen after several simulations and was considered as one of the most suitable for an urban area of dimensions as Trieste, similarly to what previously developed in other researches on urban areas where a 300m bandwidth is used (Thurstain-Goodwin and Unwin, 2000).

[5] Other kernel functions can be used, as the normal, the triangular or the uniform ones. This depends on the importance, and therefore on the weight, we want to assign to events according to their distance from the cell's centre. When using a quartic function closer events to the cell are weighted more than those located on the external border of the searching function.

Higher values of the searching bandwidth cause an excess of smoothing of the density function and therefore a higher dilution of events across the study region, while narrower ones can produce a function characterized by too many 'peaks and valleys'[6]. The function provides also a measure of accessibility, showing for each cell the events that can be reached within a certain distance, assigning a higher importance to closer events, as expressed by the weight inserted in the quartic function. The 400 meters can be considered as the average walking distance in 5 minutes. In this case the 400 m distance is furthermore obtained by means of a nearest neighbor computation using a K = 50 rank that means computing for each dataset the average of intra-events distances of different orders (Chainey et al, 2002). Therefore the control of the variable is moved from the bandwidth to a k-nearest neighbor choice. In such sense it is possible to adopt a method that, although involves different bandwidth distances for different datasets, does consider the spatial distribution and organization of events within a study area.

The function has been therefore used to estimate the number of events within 400 meters from each reference cell, counting and weighting them according to their distance from a cell's centroid according to a decreasing function and dividing the value by the area underneath the same function. Each cell is therefore attributed a relative density value corresponding to the number of events within 400 metres from the cell weighted by their distance from the same cell and divided by the area underneath the function.

Cells of relative density were mapped as a 3D function and isolines corresponding to homogeneous density values have been obtained. For the thematic classification of the density surface positive standard deviation values were used[7], following Chainey et al. (2002) we adopted a method based on mean or standard deviation for deriving isolines suitable for suggesting possible delimitation of the CBD. Here a standard deviation method is portrayed, although the mean-based one is also providing similar results. In the first case as shown in Figure 3, denser cells, and therefore those having the higher concentration of central activities, can be observed in the central area of the city where the density surface presents a relevant 'peak' if compared to the rest of the municipality of Trieste. This is also confirmed by the number of activities located in the area. Nearly 64% of the activities considered, these corresponding to 1,532 over a total value of 2,394, are located within the more external isoline in Figure 3 (right), that is the one delimiting the area above one unit of standard deviation over the mean value, with a minimum density value of 288.45 activities/km^2 and an average of 926.18 activities/km^2 in the enclosed area. The other standard deviation values (two, three, four units and more) delimitate smaller and more concentrated areas, highlighting a true 'peak' in the density surface.

In order to delineate the area where the CBD is likely to be located we examine the tail values of the density function, starting from two standard deviation units, with

[6] In an extreme case of a too narrow bandwidth, not much more information than the simple observation of the spatial distribution of events is supplied.

[7] It is frequent that several events in space do not present a normal distribution, moving towards one of the tails of the distribution itself. This is due to the tendency of several phenomena, as population and other human activities, of grouping together (Harris et al., 2005).

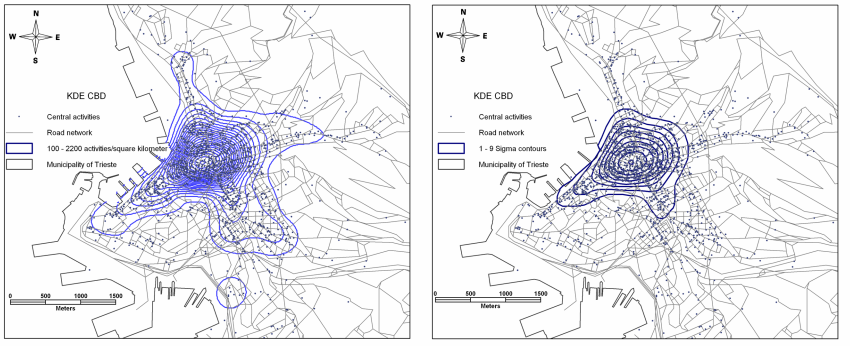

Fig. 3. Isolines of central activities density function in the city of Trieste. Quartic KDE, 400 m bandwidth (K=50). Lines spaced by density values multiple of 100 activities/km^2 (left: 100 – 2,200) and by density value multiple of 1 standard deviation (right: 288 – 2,047 activities/km^2). Mean = 68.58; Standard Deviation = 219.87; Max = 2,250 activities/km^2.

particular reference to those values higher than three[8]. The borderline of the cells belonging to such value delimitates an area of 0.75 km^2, covering 47% of the activities located in the whole territory of the Municipality of Trieste (1.130 events), delimited by the 728 central activities/km^2 isoline and with a mean density of central activities of 926.18/km^2, versus an average municipal density for Trieste of 28.25/km^2. Here 48% of banks and insurance companies branches (124 events over 259), are present, that represents the 11% of all activities in the three standard deviation area, making it a candidate for representing the borderline of the CBD of Trieste.

Central functions tend therefore to be concentrated in a circumscribed area of the city of Trieste that, as seen above, presents an evident peak to demonstrate the high density of the considered activities and a monocentric structure. It must be however noticed the alignment of many activities along some main roads as observed in the 'simple' data scatterplot. We can particularly notice a decreasing density and its elongation along the seaside main road and its parallel streets, close to the central part of the city and following a Northeast – Southwest orientation in the southern part of the city, along a North - South axis in the northern area of the central part of the city, starting from the railway station and also a North - South axis in the South – Southeast part of the city. The more smoothed and rounded shape of the function in the eastern part of the city highlights an East – West main axis represented by parallel streets characterized by central activities, while there is a fuzzier distribution along an East – Northeast axis.

Figure 4 confirms visually what is observed by means of isolines obtained through standard deviation – as in Figure 3, providing profiles of the 'cone' of economic activities in the centre of Trieste, thanks to the uniform spacing in terms of central functions' density, portraying a quite sharp decrease of density activities out of the same centre.

[8] Chainey et al. (2002) propose the method based on the standard deviation units for delimiting the border of hot-spot areas, suggesting a value of three units among the most suitable ones for this kind of analysis.

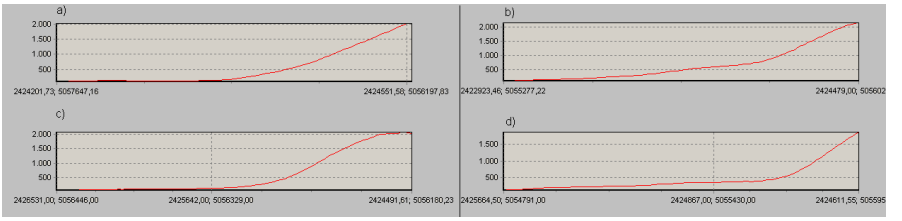

Fig. 4. Profiles of the density function in the city of Trieste following main axes. a) North-Northwest - Centre; b) West-Southwest – Centre; c) East-Northeast - Centre; d) South-Southeast – Centre.

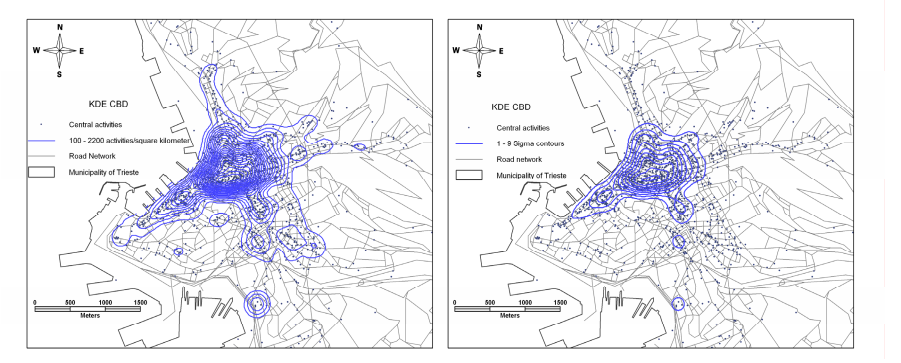

Fig. 5. Isolines of central activities density function in the city of Trieste. Quartic KDE, 255 m bandwidth (K=25). Lines spaced by density values multiple of 100 activities/km^2 (left: 100 – 2,200) and by density value multiple of 1 standard deviation (right: 305 – 2,151 activities/km^2). Mean = 74.39; Standard Deviation = 230.78; Max = 2,175 activities/km^2.

We experimented also the application of a different bandwidth based on nearest neighbour analysis, and particularly relying on a K = 25 order, that producing a 255m bandwidth.

Results are portrayed in Figure 5, where isolines are derived from the 3D function and respectively spaced by 100 units of activities/km^2 (left) and standard deviation values (right). The central peak of CBD activities is maintained reducing the bandwidth, however it is more evident that activities out of the cone are oriented according to the direction of main road axes accessing the city centre. Also, some minor clusters appear in other parts of the city.

4.2 Udine and Its CBD

A similar procedure was followed for the analysis on Udine area, with a 20m mesh overlaid onto the study region centred on the Municipality of Udine. Given the spreading of activities over an area wider than the pure Municipality, neighbouring municipalities were considered, mainly in the northern area, for the kernel density estimation, while analysis and comments are based on the Municipality of Udine. In order to compare the results for the two areas, a quartic function was used for the kernel

density estimation, using a 389m bandwidth. This value came out from the nearest neighbour computation over the activities in the wider Udine area and corresponding to a K = 50 nearest neighbour value. The distance is quite close to the one used in Trieste and that helps in the comparison of results, thus also inducing to notice some similarities in the density function' shape in the two areas.

The density function was converted in isolines, both represented in Figure 6 as spaced by 100 activities/km^2 (left) and also by values of standard deviation (right). The activities in the city of Udine are clustered in the area of the historical centre of the city, mainly in that enclosed within one of the old city walls.

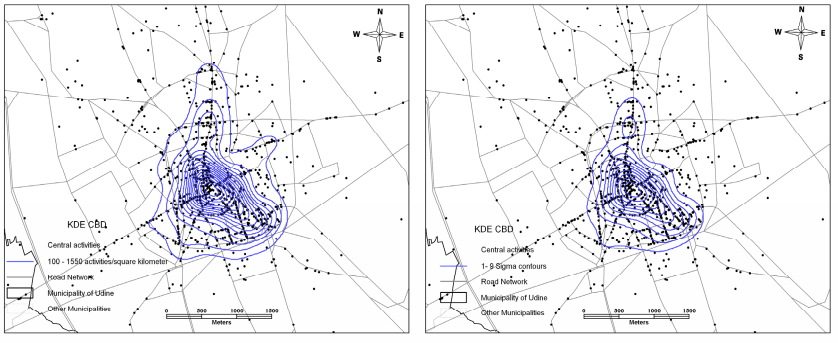

Fig. 6. Isolines of central activities density function in the city of Udine. Quartic KDE, 389 m bandwidth (K=50). Lines spaced by density values multiple of 100 activities/km^2 (left: 100 – 1,500) and by density value multiple of 1 standard deviation (right: 188 – 1,621 activities/km^2). Mean = 45.26; Standard Deviation = 143.29; Max = 1,570 activities/km^2.

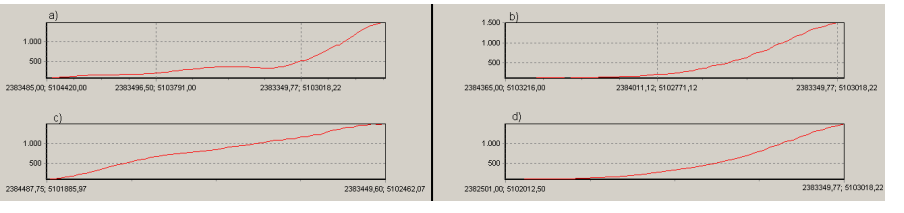

Fig. 7. Profiles of the density function in the city of Udine following main axes. a) North-South - Centre; b) Northeast-Southwest – Centre; c) Southeast-Northwest - Centre; d) Southwest - Northeast Centre.

A monocentric structure is quite evident, as in the case of Trieste, although with lower density values, with a central shape elongated towards Southeast, as well a general alignment of activities along main access roads to the city centre can be noticed. This is evident when we look at the North-South and Southwest – Northeast access roads. Standard deviation values used to delineate isolines offer interesting elements for discussion. The first value of standard deviation (188 activities/km^2) enclose an area where 69% of activities of the Municipality concentrate (1,159 over 1,685), producing a mean value of 559 activities/km^2. Higher standard deviation values correspond to more concentrated areas.

These results are also evident when we look at the density profiles obtained, portraying (Figure 4) a cone of high density of activities elongated towards the Southwest axis (Figura 4 c). We can observe it decreases quite regularly, while the other profiles (Figure 4 a, b and d) present a sharp fall of the density values when moving out from the central area.

In order to test different bandwidth and scales of analysis, a 265m bandwidth was also tested. It corresponds to a K = 25 nearest neighbor value. The same message of a monocentric structure is delivered, with an elongated shape and with some privileged axis along main access roads. Furthermore, a closer scale of analysis allows to highlight minor 'sub-centers' located outside the core of the city's CBD (Figure 8).

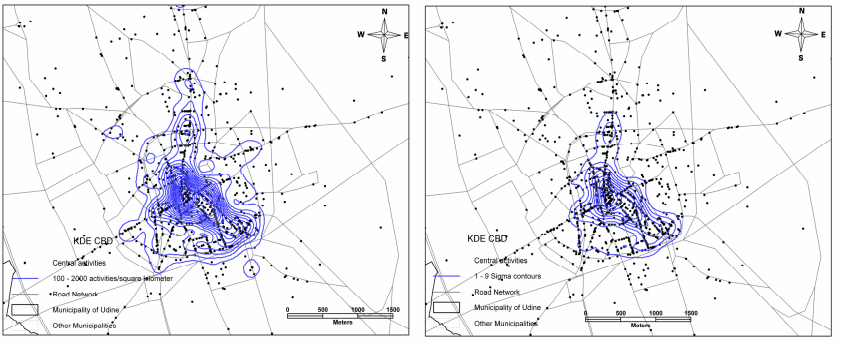

Fig. 8. Isolines of central activities density function in the city of Udine. Quartic KDE, 265 m bandwidth (K=25). Lines spaced by density values multiple of 100 activities/km^2 (left: 100 – 2,000) and by density value multiple of 1 standard deviation (right: 305 – 2,151 activities/km^2). Mean = 62.61; Standard Deviation = 180.01; Max = 2,011 activities/km^2

4.3 Comparisons

Standard deviation values were chosen to produce isolines suitable for delimiting a CBD area, and particularly values of three, four and five standard deviation units seemed to produce interesting results as 'candidates' for bordering a CBD, or, in any case, to define an area definable as truly 'central'. As suggested by Chainey et al (2002), standard deviation values can be used to define 'hotspots', however what is this value is what still need to be determined. Values higher than three standard deviation units seem to be suitable in highlighting areas of high and growing concentration of (central) activities, given both their number and the surface of the area enclosed by such isolines. Furthermore, as in the two cases examined, being such isolines quite narrowly spaced, the differences between these units are not so huge. By observing Figure 9, we can notice that the more external three standard deviation isoline seems to be capable of delimiting a 'central area'.

This is true both for Udine, where such line touch two important nodes in the road network that actually represent the access to the historic centre (limited road traffic zone), and for Trieste, where the standard deviation isoline follow some roads enclosing the city centre, two main squares and access points to the geographical centre. Higher standard deviation values, as five, can help in delineating the 'true' CBD, as

can also be noticed observing Table 4. A limited area (0.40 km^2 in Trieste and 0.46 km^2 in Udine) still encloses a high percentage of all the activities in the municipality (over 35%) and consequently very high rates in terms of density values.

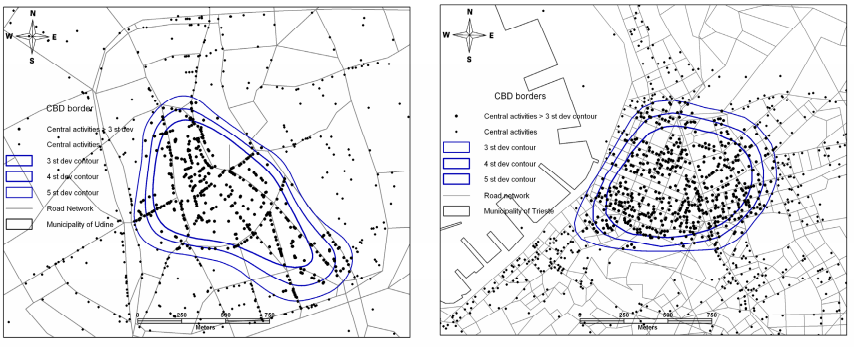

Fig. 9. Selected isolines of central activities density function in the cities of Udine (left) and Trieste (right) with standard deviation values of 3, 4 and 5 as 'candidates' for delimiting CBD area

Table 4. Central activities and their distribution in areas defined by standard deviation values

Region	Activities (*Banks & Insurance*)				Area km^2		Density activities/ km^2	
	Ts	% (*B&I over total*)	Ud	% (*B&I over total*)	Ts	Ud	Ts	Ud
Municipality	2,394 (*259*)	100.00 (*10.65*)	1,685 (*194*)	100.00 (*11.51*)	84.73	56.87	28.25	29.63
3 st. dev isoline	1,130 (*124*)	47.20 (*10.97*)	806 (*74*)	47.83 (*9.18*)	0.74	0.85	1,524.08	950.14
4 st. dev isoline	1,002 (*112*)	41.85 (*11.18*)	719 (*65*)	42.67 (*9.04*)	0.55	0.63	1,811.30	1,143.00
5 st. dev isoline	843 (*105*)	35.21 (*12.46*)	615 (*55*)	36.50 (*8.94*)	0.40	0.46	2,098.74	1,343.33

Ts = Trieste; Ud = Udine; Banks and insurance companies figures in brackets and italics. Percentage values related to activities are referred to the total figures in the municipality. Percentage values related to banks and insurance companies are referred to the total number of activities for each of the sub-areas considered.

The differences between the two urban areas must also be noticed. Although the mean density values for the two cities are quite similar, if the activities are related to the overall surface of the Municipality, things change when we look at more limited areas and the activities located there. In the Trieste area as we move towards the true centre the density rises to more than 2,000 activities/km^2, while the value in Udine just overcomes 1,343. More interestingly, the kind of activities change as well, with a

considerable number of banks and insurance companies branches concentrated in Trieste, whose percentage on the overall activities grows, while in Udine such concentration of financial services is less clustered and room is left to professionals.

5 Conclusions

5.1 General Notes

Central Business Districts have been studied in the past as the areas with high value activities take place in an urban area and give it the attribute 'central'. To-date things have changed, with major companies and head offices moving out from the center of cities and locating in semi-peripheral business districts. However city centers are still lively and host a wealth of activities still considerable as central. These include leisure and other ones related to people work life and also free time. Classical theories on urban functions, forms and shape can however be rethought to date and studied again, adapting some characteristics to the changes intervened. In such sense the data available and GIS and geocomputational tools can help and provide scholars, as well as planners and decision makers, with means of analysis, representations and discussion over a territory in order to understand its characters. The starting point is the geographical location of activities, processed to obtain density surface that can produce isolines whose values are under exam as candidate elements to delineate area of really 'central' activities and functions. The analysis was performed over two mid-size neighboring cities in Northeastern Italy, although there is still a need to test the methods on other urban areas, as well to examine more in depth the composition of activities within the dataset in order to better understand the different 'central activities' that characterize different cities.

5.2 Local Results

With the limitations afore said, we find two different situations for the city considered, both in terms of density and variety: Trieste is characterised by a prevalence of banking and insurance activities, which are clearly clustered (as the density ratio shows) and which follow the main road axis. Udine, instead, is characterised by a prevalence of professional and consultancy activities which, differently from Trieste, are not clustered, but are located along an ideal North-South axis. The aim of future researches on this topic will be the one of finding out, for each kind of sub-category, the relative density distribution and its contribution to the overall function, furthermore considering infrastructural and geomorphologic features as well as the urban structure as driving elements for the spatial pattern. That could allow obtaining a more refined analysis where simplistic assumptions of homogeneity and isotropy of space are relaxed.

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