

A Modified DBSCAN Clustering Method to Estimate Retail Center Extent

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This research introduces a new method for the identification of local retail agglomerations within Great Britain, implementing a modification of the established density based spatial clustering of applications with noise (DBSCAN) method that improves local sensitivity to variable point densities. The variability of retail unit density can be related to both the type and function of retail centers, but also to characteristics such as size and extent of urban areas, population distribution, or property values. The suggested method implements a sparse graph representation of the retail unit locations based on a distance-constrained k-nearest neighbor adjacency list that is subsequently decomposed using the Depth First Search algorithm. DBSCAN is iteratively applied to each subgraph to extract the clusters with point density closer to an overall density for each study area. This innovative approach has the advantage of adjusting the radius parameter of DBSCAN at the local scale, thus improving the clustering output. A comparison of the estimated retail clusters against a sample of existing boundaries of retail areas shows that the suggested methodology provides a simple yet accurate and flexible way to automate the process of identifying retail clusters of varying shapes and densities across large areas; and by extension, enables their automated update over time.

Introduction

Town centers form the core of many urban areas and are characterized by clustering of various types of socio-economic activities with retail and related services being pivotal. They can be viewed as complex economic systems that constantly evolve (Thurstain-Goodwin and Unwin 2000) and therefore their composition and spatial extent are likely to expand or contract over time. This evolution has been linked to changes in the planning system, rising property values, changing levels of accessibility, other forces of change such as economic shocks or more gradual changes such as the rise of Internet sales (Singleton et al. 2016).

It has long been recognized within multiple international settings, that the aggregate national structure of consumer spaces and shopping destinations are complex (Berry 1967); with retail cluster size and function relating to their attraction, market potential, competition,

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and agglomeration benefits. Within many contexts traditional shopping destinations that have evolved naturally and appear well-embedded within the urban fabric (including town centers), are supplemented by purpose-created retail opportunities such as regional shopping centers, retail parks, strip malls, or focused shopping destinations such as designer outlets (Teller and Reutterer 2008). Although it has been argued that depicting retail agglomerations for a national extent, and particularly accounting for more granular temporal shopping patterns is very challenging (Mackanness and Chaudhry 2011); the classification of shopping destinations and delineation of their spatial extent is essential to gaining a better understanding of the relationship between use of retail space and changing consumer behavior. A consistent and rigorous approach to defining town center boundaries enables systematic metrics of retail center morphology and performance to be actualized (Thurstain-Goodwin and Unwin 2000), alongside providing utility as input into many commonly implemented retail analytics tasks related to store location and demand estimation (Newing, Clarke, and Clarke 2015).

In the case of England and Wales, a national set of town center boundaries were developed by Thurstain-Goodwin and Unwin (2000) and subsequently adopted by the Department of Communities and Local Government (DCLG) in 2004. Their approach was to generate surfaces of spatial densities using kernel density estimation (KDE), from socio-economic variables including building density, diversity of building use, and tourist attraction (Mackanness and Chaudhry 2011). In addition, their approach aimed at delineating town centers, however, such zones are more expansive (e.g., by including office space) than those that might be related mainly to retail. As such, one of the objectives of this work is to move away from a more general definition of town center locations as centers for employment, to a more functional measure of spaces delineated for retail and services. Furthermore, in many cases, the extent of the 2004 DCLG town center boundaries will likely have changed over the past decade, eroding the utility of these previous models for contemporary applications. Finally, the availability of more accurate and comprehensive spatial data on retail unit locations in Great Britain (G.B.) has improved significantly since this time, which provides scope for exploring a new robust method of defining the spatial extent of retail agglomerations. As such, this article highlights deficiencies in a number of existing cluster analysis methods for retail center definition before presenting a density-based clustering technique that can consistently identify retail areas, is updatable over time and can be applied to wider national extents. We implement this analysis using a national data set of retail and service locations, and evaluate the center definition outcomes at a local level.

Where are retailers located?

A national occupancy data set of 529,062 retail locations across G.B. was provided by the Local Data Company through the ESRC Consumer Data Research Centre and was collected via a large pool of local surveying teams during 2015. The data contain detailed information about the current occupier and location of retail unit and service premises. While a full post-code was available for all surveyed premises (enabling geocoding proximal to ~13 properties), more precise latitude and longitude coordinates were available for 437,260 units (about 82%), which were retained for further analysis; thus providing building level of accuracy. Other collected information for each location included the fascia (a surrogate for occupier) and the type of retail or service business (i.e., leisure, comparison, service, and convenience) including

vacant outlets. For retail units located in shopping centers, retail, and leisure parks the respective name of the shopping center or retail park was also provided.

Conceptually, utilizing vacant units in the identification of local retail agglomerations may be problematic given that these voids may often occur as a result of failure of a particular retail setting (Benjamin, Jud, and Winkler 2000), and as such, an indication of potential change in extent morphology. For this reason, all vacant units were removed from the data set. Additional processing also removed units that were classified as auto services that are not typically considered part of retail agglomerations. Furthermore, miscellaneous (not related to retail or unclassified units) were also excluded. The final cleaning operation identified and removed duplicate locations (i.e., points with identical coordinates or within very close proximity), which can unduly influence clustering results as well as the identification of outliers. These duplicate locations were typically the result of the two-dimensional representation of retail units within multi-storey buildings. Thus, the removal of duplicates (any points within a 2 m radius from another point) was carried out.

Estimating retail center location and extent; methods, and calibration

Cluster analysis is a collection of unsupervised learning methods that address the issue of grouping a set of objects based on similarity. Many commonly used clustering algorithms make group allocations with the objective of increasing similarity within a cluster and increasing dissimilarity between clusters. Other commonly used clustering techniques such as density-based algorithms seek dense regions separated by low density regions, while model-based methods assume that the data come from a mixture of probability distributions, each of which represents a different cluster (Gan, Ma, and Wu 2007). Cluster analysis is a multivariate technique (multiple attributes of the phenomenon under investigation can be used), but in this study it is strictly spatial; utilizing only the locations of the retail units. This is an appropriate approach for the identification of retail agglomerations where the extent of the clusters is determined by spatial discontinuity in unit distribution (Dearden and Wilson 2011).

An important consideration when clustering spatial data is to select a method that is sensitive to the distinction between clusters that are either compact or chained (Gan, Ma, and Wu 2007) and additionally, can identify outliers outside of primary observed geographic distributions. Within a retail context, examples of compact clusters could include those retail units residing within a city or major town center such as Wolverhampton (West Midlands) (Fig. 1A), often with connecting voids that are pedestrianized. Chained retail clusters, conversely, often can be observed along the road network (these are often known as “high streets” in G.B.), such as Clapham Junction (London) (Fig. 1B).

To estimate the definition of retail centres, the following clustering methods were evaluated: Density based spatial clustering of applications with noise (DBSCAN) (Ester et al. 1996), quality threshold (QT; Scharl and Leisch 2006), KDE (Azzalini and Torelli 2007), random walk (Csardi and Nepusz 2006), and K-means (Lloyd 1982). As will be described, all of the clustering methods evaluated require the calibration of tuning parameters that we selected to optimize using the S_Dbw internal evaluation indicator (Halkidi and Vazirgiannis 2002), which has been found by Liu et al. (2010) to provide better results compared to seven other internal validation indexes. It is defined as the sum of the mean dispersion (S) in the clusters and of the between-cluster density (G) (Desgraupes 2013):

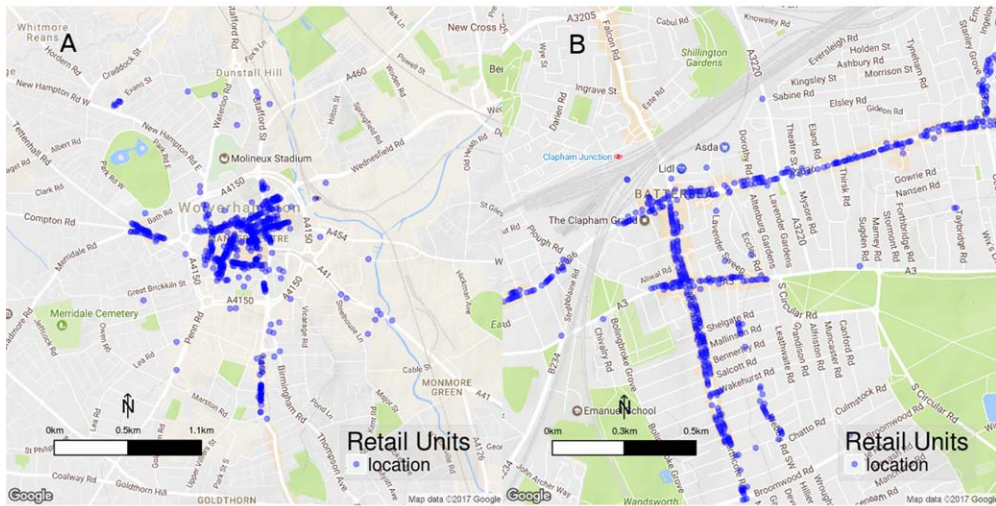


Figure 1. Wolverhampton (left) and Clapham Junction in London (right) are examples of compact retail cluster and chained retail cluster, respectively.

$$S_Dbw = S + G \quad (1)$$

As such, the process of calibrating each clustering method was carried out prior to implementation in the evaluation by identifying suitable starting values (for those tuning parameters that a single value could not be determined), then producing a number of different models within a range of values and finally selecting the optimal model based on the S_Dbw index (i.e., selecting the parameter values of the model with the smallest S_Dbw value).

DBSCAN (Ester et al. 1996) was selected as it is one of the most prevalently implemented spatial clustering algorithms that is able to find arbitrarily shaped clusters and to handle outliers (Gan, Ma, and Wu 2007). In addition, with the use of kd-tree indexing this was the computationally fastest method tested. The greatest drawback of DBSCAN is limited sensitivity for data sets with varying densities (Everitt et al. 2011). Our optimization for the epsilon (radius) parameter started by calculating the distance to the four nearest neighbors for each point (Ester et al. 1996). The distances were then sorted in ascending order and the 95th percentile value was selected as starting epsilon. Even though this is a simple technique, k-NN distance has been found to be a reliable proxy of local density and outlier detection, outperforming even newer and more complicated methods (Campos et al. 2016). The minimum points parameter was set equal to 10, which is the minimum number of retail units required for an area to be classified as local center (Wrigley and Lambiri 2015). Following this, the DBSCAN method was calibrated by allowing the epsilon value to vary within the range of ± 20 m from the starting epsilon value. Using 5 m intervals, the best clustering solution from nine DBSCAN models for every study area was selected with the S_Dbw index. Within the study sites, the 20 m range was used as it was found to be large enough to test as many models as possible without being an extremely demanding task, while the 5 m interval was small enough that any difference between models using a smaller interval was negligible.

Non-parametric density estimation (Azzalini and Torelli 2007; Azzalini and Menardi 2014) combines both KDE and a graph model that connects retailers into a network by

proximity. In this process, KDE is used to identify a number of core clusters with density above a certain threshold from within the spatial distribution. These are then used to create connected regions of points (subgraphs) by means of Delaunay triangulation. The technique requires definition of a parameter value that is multiplied by the smoothing vector of the kernel estimator. This was determined through comparison of retail boundaries delineated by respective local authorities to outputs created with the clustering method. Suitable values for the smoothing parameter varied between 0.4 and 1.1. Lower values resulted in too fragmented clusters, while higher values over-smoothed, creating large and also unrealistic clusters. Multiple models were tested, varying the smoothing parameter value using 0.05 intervals, and again selecting the optimal clustering with the *S_Dbw* index. A key advantage of this method is that it is nonparametric (it does not make any assumptions concerning the probability distribution), and thus is more suitable to identify clusters of varying shapes and densities. However, it is also a stochastic method, and as such it requires optimization, which has the disadvantage of increasing computation times.

The QT (Scharl and Leisch 2006) identifies clusters after specification of two parameters: the maximum diameter of the clusters and the minimum number of neighbors within a cluster. The minimum number of neighbors was set equal to 10 which aligns to a formal definition of a retail center within the United Kingdom (Wrigley and Lambiri, 2015). Through testing within different contexts, the optimal radius value was highly sensitive to retail unit density variation. After consideration of the *S_Dbw* index, the radius parameter was allowed to vary between 100 and 400 m with 50-m intervals for smaller urban areas (e.g., Abertillery) and between 300 and 1000 m with 100-m intervals for larger urban areas (e.g., Bristol). The algorithm initializes by randomly selecting a point as a center of a cluster and then, for as long as the diameter is smaller than a user specified value, it iteratively adds a point to the cluster so as to minimize the increase in the cluster diameter. This process is repeated for a random number of sample center points that satisfy the condition of having at least one neighbor within the specified diameter threshold. After the largest candidate cluster is identified and removed from the data set the process is repeated for as long as there are no remaining clusters with size greater than the neighbor threshold. The method is also computationally intensive due to being stochastic.

Random walk was tested which is a graph-based method that is based on the Walktrap algorithm (Pons and Latapy 2005). The algorithm finds densely connected subgraphs based on the assumption that random short walks tend to stay within the same densely connected subgraph. Initially, the algorithm partitions the graph into a number of subgraphs and then computes the distances to all adjacent vertices. Subsequently, for each iteration it chooses two subgraphs to merge if they are adjacent and if they minimize the squared distances between the vertices. The output is a dendrogram where the leaves are the vertices and each edge is a connection between subgraphs. The best partition of the graph is the one that maximizes a modularity criterion (Newman 2004). Optimization found that the method required a maximum number of 50 steps to find the best model using the *S_Dbw* index.

The final algorithm tested was *K-means*, with the only parameter requiring specification being the number of *K* clusters. Initially, the algorithm allocates objects randomly to each cluster and, subsequently, iteratively assigns the objects to the nearest cluster according to a distance measure until either the distance measure or the membership of the clusters do not change significantly. This method has low computational complexity, however, produces clusters with convex hull shapes and it does not always identify outliers, that is, all objects are clustered although may return outlier clusters with very small case frequency. In addition, the

method is also stochastic, and therefore requires optimization through multiple runs which occurs at the expense of computational time. Information obtained from the application of the other clustering methods was used to calculate the starting value of the number of clusters as the mean number of the clusters identified by DBSCAN, KDE, QT, and random walk. Subsequently, the method was calibrated by producing 11 models with the number of clusters varying within the range of ± 5 clusters from the starting value and the optimal model was selected based on the S_Dbw index.

In addition to the aforementioned methods, the chameleon (Karypis, Han, and Kumar 1999), fast greedy (Clauset, Newman, and Moore 2004) and ensemble (Hornik, 2007) methods were also tested but are not used for the evaluation. Chameleon was not included given difficulty in automating the process of identifying optimal values for its six tuning parameters, fast greedy is a graph-based method that did not provide better results than the random walk and finally the ensemble method was particularly demanding in terms of computer resources for a nationally extensive application. Obviously, there are a plethora of other methods that have been shown to be useful for clustering spatial data such as the DBCLASD method (Xu et al. 1998). However, an important factor for inclusion in the evaluation was that the methods were accompanied by useful documentation that facilitated their implementation. In addition, that there was indication they were under active development or well established, and were available within most programming languages.

Center definition and evaluation

The five candidate methods were evaluated over eight case study areas that are representative in terms of G.B. retail location density and size. These included: Abertillery and Cardiff in Wales, Bristol, Clapham Junction, Winchester, and Wolverhampton in England, Glasgow and Inverurie in Scotland (Figs. 2 and 3).

Although there is a larger pool of other representative areas, within these specific locations additional supplementary data were also available for cross validation and included two sources. First, local authorities within the United Kingdom are required to perform a town center “health check” (National Planning Policy Framework [NPPF] 2012), which typically requires them to delineate boundaries for retail centers. Even though the reports produced by the local authorities contain rich information, the publicly available boundaries can typically only be accessed in rendered pdf format. Given that a small number of (qualitative) comparisons can be made against these sources without extensive redigitizing, the reports were used to assist with input parameter specification and testing during the calibration process described in the previous section. Second, boundaries for the 339 largest “retail places” in the United Kingdom were acquired from the company Geolytix, and although they represent only a subset of total retail boundaries, they nevertheless provide an additional and relatively large sample of independent retail areas suitable for comparison.

Finally, within evaluation that follows, all clusters (identified by each clustering method) that had less than 10 retail units were removed, which as noted earlier, is the minimum threshold considered to be as part of a center. Additionally, for those clustering solutions that additionally identified outliers from the main distributions, these locations were also removed.

The remainder of this section presents the outputs of the clustering methods for two of the larger more complex study areas: Bristol and Glasgow, alongside an overall set of evaluation results for all case study locations.



Figure 2. The locations of the eight case study sites in Great Britain.

Bristol has a greater than average number of retail units (2,456), high variability of retail density and potential occurrence of different cluster shapes. The location of the retail units (blue dots) are shown in Fig. 4 alongside labels colloquially used for the various retail centers and their boundaries as defined by the respective local authorities.

In the past, Broadmead was recognized as the principal shopping center of Bristol, but recent studies (Bristol City Council 2008 [unpublished]) suggest that the boundaries of Bristol should be expanded to include the high streets of Stokes Croft south of Ashley Road (depicted as sparse dots in Fig. 4), Christmas Steps and Old Market. The most recent Local Plan from

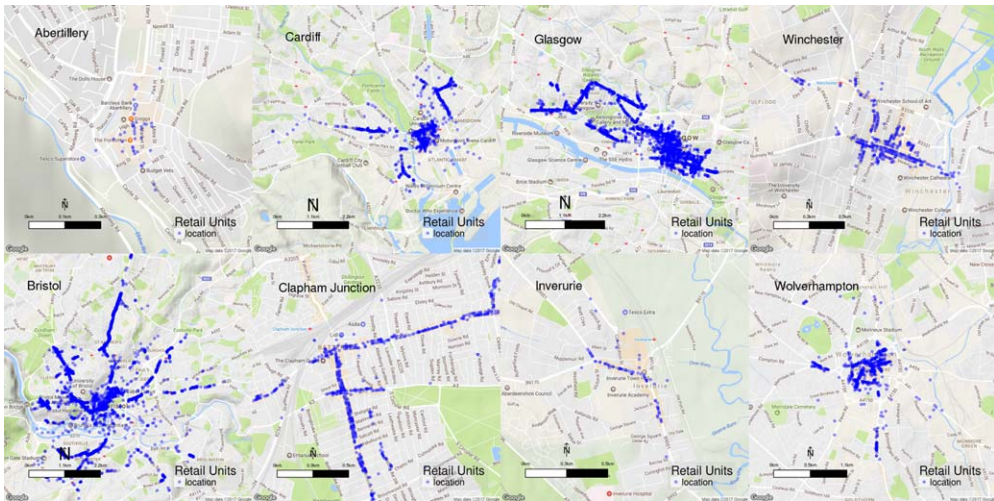


Figure 3. Spatial extent of the eight case study sites.

2015 (Bristol Central Area Plan [BCAP], 2015), which is required by law, defines precisely the boundary of a wider Bristol city center, however, the spatial extent of the individual so-called shopping, services and the evening economy areas is less specific as these areas often have overlapping functions. The Local Plan defines the primary shopping area as Broadmead and Queen's Road; in addition, it defines the primary shopping frontages (Broadmead and part of Queen's Road and Old City), secondary shopping frontages Stokes Croft, Old Market, Victoria Road, and parts of Queen's Road and Old City and leisure use frontages (part of Old City and Broadmead).

The first clustering algorithm to be evaluated was DBSCAN, which identified 26 clusters in the study area as can be seen in Fig. 5 (outliers are denoted by 0). Stokes Croft is part of the city of Bristol (with the cluster boundary extending north of Ashley road), however, Old Market is not. There is a good separation from the Gloucester Road cluster that has been identified correctly as a single cluster. Clifton, Whiteladies and most of the town center have also been identified as separate clusters. Within Bedminster, the western part of the area was, however, identified as a separate cluster, most likely due to higher local density. The KDE method identified 11 clusters with a cluster for the city center being fairly accurate, matching the local authority defined boundary. However, it is obvious that the method identified fewer clusters than might be expected given the overall retailer distribution. The clustering solutions generated by QT, K-means, and Random Walk were somewhat similar in that they identified separate clusters in areas that are strongly connected (e.g., Bristol city center, Gloucester road) while they clustered together points that are weakly connected (e.g., Totterdown and Well road for QT and K-means, Queen's road and Clifton for Random Walk). A further problem with the methods is that they identified few outliers, which results in the identification of very sparse clusters.

With 2,347 retail units, Glasgow is the second largest study area in the analysis (Fig. 6). There is one metropolitan retail center (Glasgow city), one regional center (Partick—Byres road) and five town centers (Calton, Crastonhill—Yorkhill, Kelvinbridge, St. George's Cross—Great Western road and Woodlands) (Fig. 6). The boundary of Glasgow city is well defined by the M8 motorway (north and west), the river Clyde (south), and the High street (west).

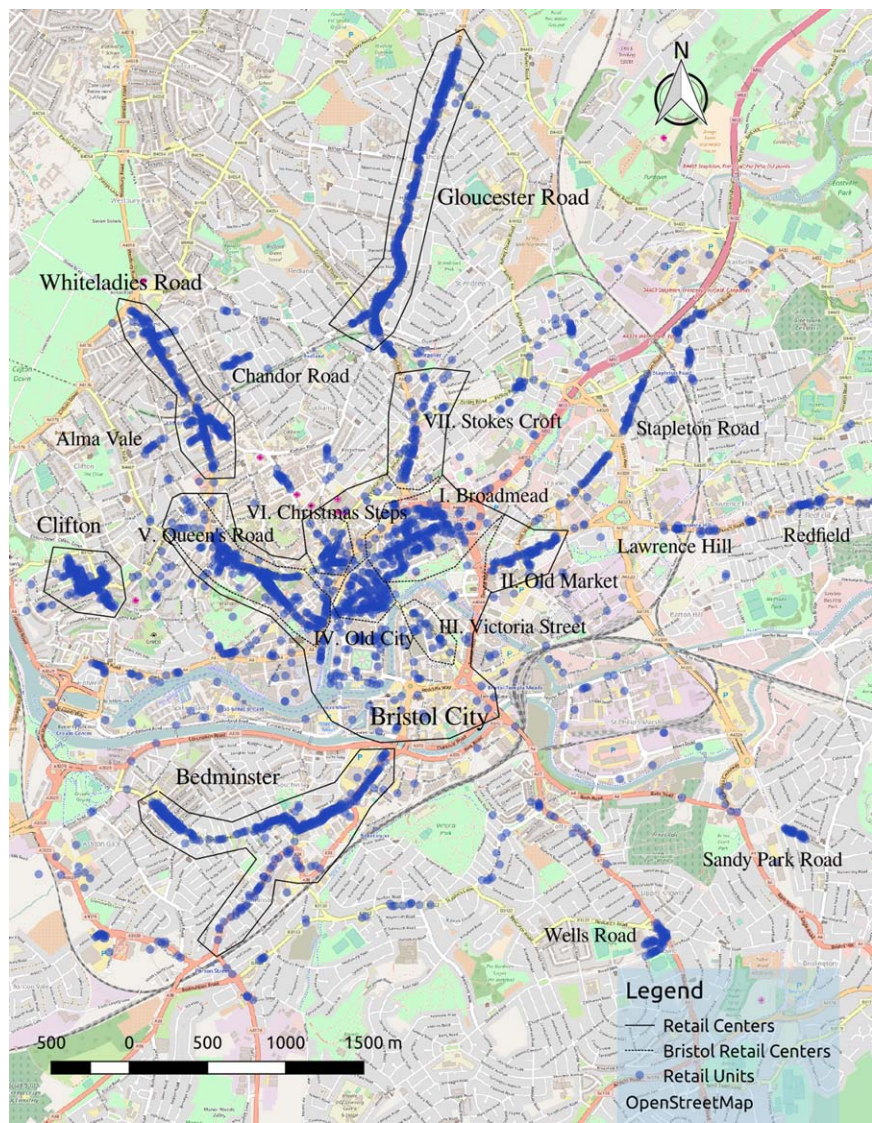


Figure 4. The study site of Bristol, blue circles represent the retail unit locations, while the boundaries of the retail agglomerations as estimated by the local authorities are represented with black lines or dots.

DBSCAN (Fig. 7) identified accurately the cluster of Glasgow city center, with only a few retail units crossing the M8 on the west of the city and south of Woodlands. The QT and KDE methods clustered the city center together with the town center of Calton. K-means and QT also merged the western part of Glasgow city with Woodlands and St. George's Cross. The output from the Random Walk had additional issues, splitting up the larger retail areas as in the case of Partick-Byres road. For that retail area, DBSCAN provided the most accurate result, however, the boundary of the cluster extended to include Kelvinbridge. Concerning St. George's Cross, the cluster obtained from DBSCAN is a close match to the boundary defined by the Glasgow city council and the same could be said for Woodlands.

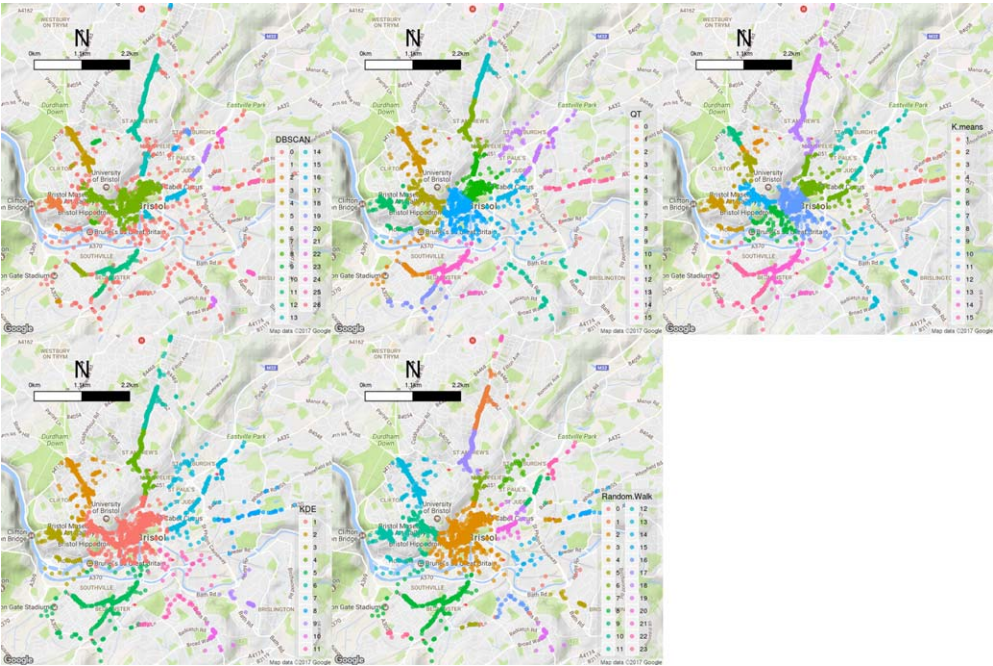


Figure 5. A comparison of the five clustering methods within the study site of Bristol.

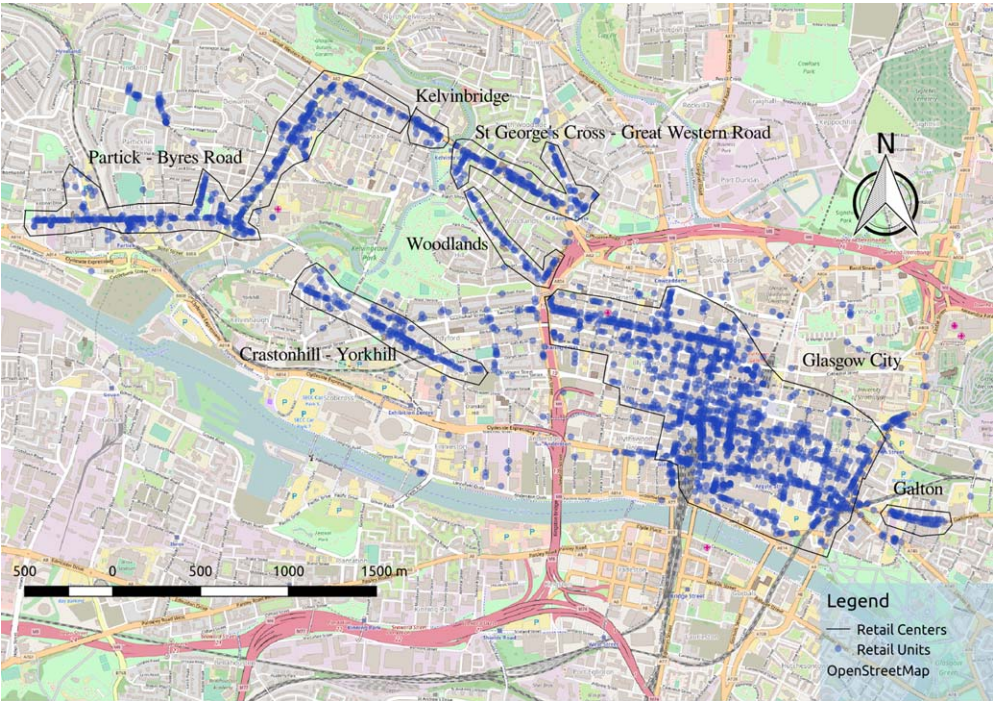


Figure 6. The study site of Glasgow, blue circles represent the retail unit locations, while the boundaries of the retail agglomerations as estimated by the local authorities are represented with black lines.



Figure 7. A comparison of the five clustering methods within the study site of Glasgow.

Table 1 presents the overall evaluation results from the qualitative comparison for all of the eight study areas. In most cases, the DBSCAN method provided results that were more consistent with those formal definitions created from the respective local authorities. Importantly, DBSCAN was the most efficient method in terms of computing resources and this is particularly significant for a national extent study. In addition, it was easier to identify starting values for the parameters of the method, while one of the strongest advantages of DBSCAN was the identification of outliers.

It is clear from the results that DBSCAN performed well for the case study selection, however, this method is known to underperform in areas where the density is not uniform (Everitt et al. 2011). Such an issue also becomes apparent when looking at the range of the optimal epsilon values that were used for the selected areas (Table 2). If a single global epsilon value

Table 1. Results from the Qualitative Comparison of the Clustering Methods in Eight Locations Across Great Britain

Case study area	Retail center type	Preferred method
Abertillery, Wales	Small town center	KDE, Random Walk
Bristol, England	Large urban area	DBSCAN
Cardiff, Wales	City center	DBSCAN
Clapham Street, England	Large high street	DBSCAN
Glasgow, Scotland	Large city center	DBSCAN
Inverurie, Scotland	Small high street	DBSCAN
Winchester, England	Historic town center	DBSCAN
Wolverhampton, England	Regional town center	DBSCAN, Random Walk

Table 2. Optimal Epsilon Values Used by DBSCAN in the Selected Study Areas

Study area	DBSCAN epsilon (meters)
Abertillery	84
Bristol	119
Cardiff	120
Clapham Junction	70
Glasgow	70
Inverurie	120
Winchester	80
Wolverhampton	91

had been used for all case studies, it would have resulted in suboptimal local results. As such, we developed a refinement to the method which involves splitting of the national-scale data into more homogeneous areas for separate treatment; with the challenge being that unlike the case study evaluations, this required automation given that coverage was for the national extent.

Development and application of a modified DBSCAN method

To address the issue of heterogeneous density, a modified approach to DBSCAN was developed by introducing three important concepts:

- (1) the combination of DBSCAN with graph data structures and algorithms that are used to iteratively partition the national study area into subgraphs of successively more homogeneous point density;
- (2) the iterative application of DBSCAN using a local epsilon value for each subgraph, followed by the selection of one cluster per iteration based on the condition that the epsilon value is representative of the cluster’s density;
- (3) the use of a third parameter termed maximum distance to constrain the points that can be members of a cluster to have at least one neighbor within a radius that is less than or equal to the maximum distance. The rationale behind this decision is that distance is an important parameter of retail spatial agglomerations, which is sensitive to gaps and discontinuities. Given that both spatial density and spatial discontinuity determine whether a point is part of a spatial cluster, the combination of k-nearest neighbors (a proxy of point density) with the radius-based constraint (a proxy of spatial discontinuity) facilitates neighboring locations within close proximity and similar point density to be members of the same cluster. Compared to a post-processing removal of points based on a distance threshold, using a distance threshold within the modeling process has the advantage of avoiding the inclusion of outliers in the calculation of the epsilon value but, more importantly, facilitates the decomposition of a graph into subgraphs of more homogeneous density.

In the first step of the proposed methodology, a sparse graph representation of the spatial data set is created based on a k-nearest neighbor matrix and the maximum distance constraint. The vertices of the graph are the locations that have at least one neighbor within the specified



Figure 8. A comparison of different k values to produce a sparse graph representation of the retail locations. Lower k values result in more homogeneous (in terms of point density) subgraphs, nevertheless, they also result in splitting sparse areas into different subgraphs.

maximum distance. Next, a Depth First Search algorithm is implemented to decompose the sparse graph to create more homogeneous (in terms of point density and distance between the retail units) subgraphs, under the condition that each subgraph has at least 10 vertices and that each location has at least one neighbor within the maximum distance. The vertices that are not part of any subgraph are removed as outliers. The maximum distance value in this study represents the maximum distance that a location can still be considered well connected to a shopping area on foot. Different distance values have been suggested as indicators of walking distance, ranging between 300 and 500 m (Rogstad and Dysterud 1996; NPPF 2012). Based upon the definition of edge of center for retail purposes in the United Kingdom (DCLG 2009), the maximum distance value was set equal to 300 m. Three k values were tested to split the study area into subgraphs, and included 4, 10, and 15 (Fig. 8). The first value was tested as it is already used as a proxy of local density and the second value was considered as it is used by the minimum points parameter of DBSCAN. As it would be expected, the lower the k value, the greater the number and the more homogeneous the density of the subgraphs that were produced. Conversely, using lower k values (between 4 and 10) can result in splitting areas with low-point density (mostly chained clusters, i.e., High Streets) into different subgraphs. For this reason the k value was set equal to 15.

Given that the spatial extent of each subgraph depends on the connectivity and number of points within an area, each subgraph can represent a town center, a city center or even a metropolitan region. DBSCAN, however, assumes that the epsilon value is a representative indicator of the local density. To fulfill that assumption, in the third step of the methodology, DBSCAN is first applied (within each subgraph) in an exploratory approach to identify and select the cluster that has density (as estimated by the local epsilon, i.e., the 95th percentile of the four nearest neighbors' distances) closer to the overall density.

Following the selection of a single cluster, all the neighboring clusters (i.e., the clusters that share a common edge in the graph) with similar density are selected along with those neighboring points that were identified by the exploratory DBSCAN as outliers. Following this, a new study area of homogeneous point density is created from the selected points and DBSCAN is applied again to identify the clusters. The selected clusters are then removed from the graph representation of the point data, and the process of using an exploratory DBSCAN model to identify a cluster and select those neighboring clusters with similar point density is

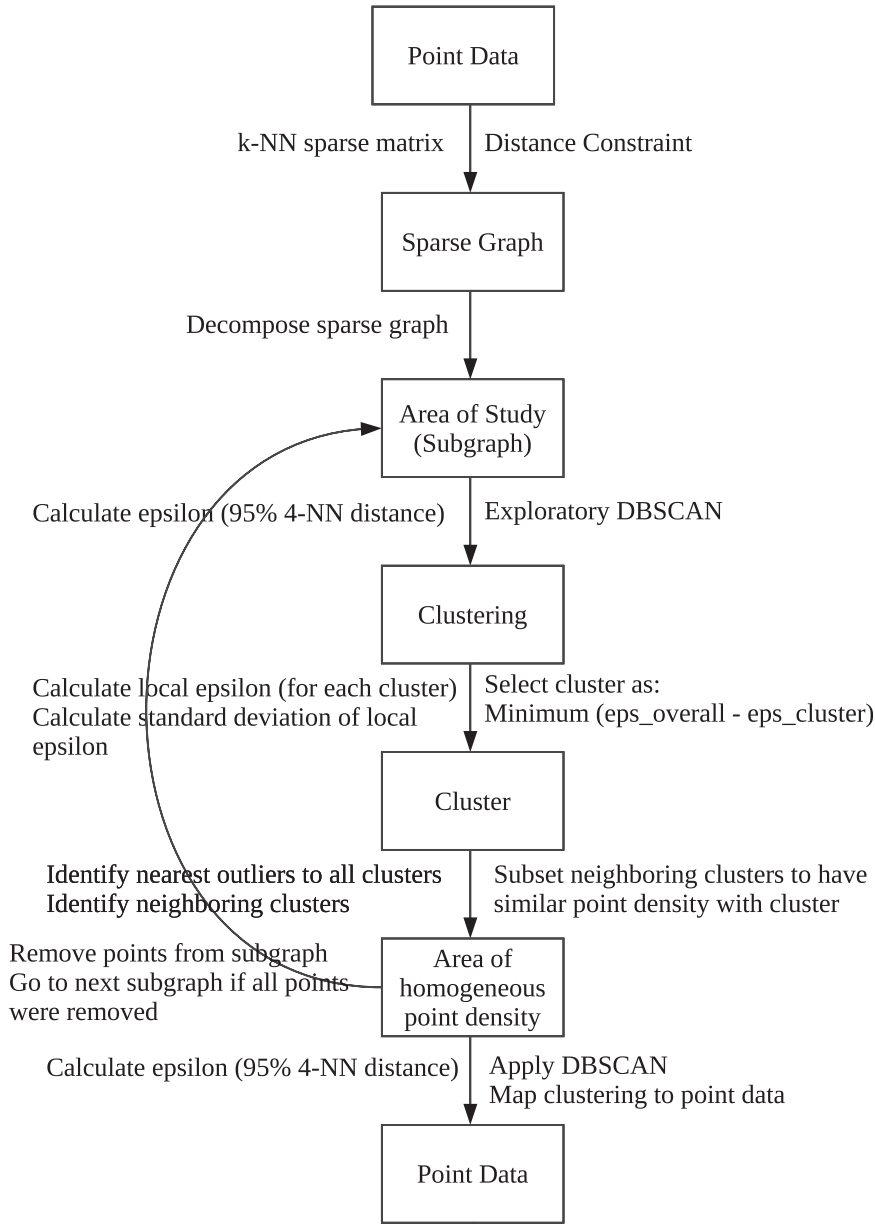


Figure 9. The point data are represented as a sparse graph using a distance-constrained k-NN sparse matrix, which is decomposed into subgraphs. DBSCAN is applied in an exploratory approach and a single cluster is selected with point density closer to the overall point density. The neighboring clusters (that share a common edge) are also selected if their point density is similar, along with the neighboring outlier points, forming thus a new area of homogeneous point density, where DBSCAN is applied. The process is iteratively applied until no cluster can be formed.

iteratively carried out until no cluster can be formed. This process is summarized in Fig. 9. It should be noted that one of the advantages of the methodology is that it is no longer required to optimize the clustering solution using the S_{Dbw} index, which results in a faster algorithm.

Table 3. Summary Values of Five Clustering Models with Different Standard Deviation Thresholds

Models	Number of clusters	Distribution of epsilon values (m)					
Standard deviation threshold	Count	Minimum	25%	50%	Mean	75%	Maximum
0.6	2,928	80	80	80	100.3	113.0	170.0
0.8	2,922	80	80	80	100.3	113.0	170.0
1.0	2,920	80	80	80	100.3	113.0	170.0
1.2	2,923	80	80	80	100.1	113.0	170.0
1.4	2,921	80	80	80	100.1	113.0	170.0

To evaluate the point density similarity among clusters, the standard deviation of point density in a subgraph was used. More specifically, those neighboring clusters with point density within 1 SD from the point density of the initially selected cluster were also selected, with the assumption being that they define an area of homogeneous point density. To test the sensitivity of the method to the standard deviation threshold, five different values were considered, 0.6, 0.8, 1.0, 1.2, and 1.4. As can be seen in Table 3, the clustering solutions are practically identical when looking at the number of clusters produced and the distribution of the local epsilon value.

For the parameter values required by DBSCAN, as detailed earlier, the value of the minimum points parameter was set equal to 10 and the epsilon value was calculated as the 95th percentile of the four nearest neighbor distance. However, the epsilon value was only allowed to vary within the range between maximum 170 m, which was found to be useful to exclude outliers from being identified as members of clusters, and a lower bounds of 80 m which was used to avoid identifying certain large shopping malls as clusters. This necessity is a consequence of the hierarchical nature of retail centers within G.B. given that the objective of the analysis was to create clusters that were inclusive of the different functional retail forms. Following the application of DBSCAN to each subgraph and the extraction of 2,920 clusters, the final retail agglomerations were compiled and each retail location was assigned an identifying number denoting cluster membership. The clusters obtained from the modified DBSCAN methodology for the selected study areas are shown in Fig. 10 and can be compared against those created by applying the traditional DBSCAN to each subgraph (Fig. 11). For the traditional DBSCAN model a global epsilon equal to 107 m was applied, which was calculated as the 95% of the four nearest neighbors distance.

When comparing the two graphs, it can be seen that in certain areas such as Bristol and Cardiff the clustering solutions are quite similar, however, in areas such as Clapham Junction and Wolverhampton the modified DBSCAN model appears to be more sensitive to gaps and discontinuities, thus identifying a greater number of clusters. Particularly for Glasgow, the modified DBSCAN method provided the only clustering solution that identified Kelvinbridge as a separate cluster in an area of high-point density that does not provide major discontinuities between clusters. At the same time, it was the only method that identified a sparse cluster south of the river Clyde and west of the M8 motorway (the epsilon value was 80 m for Kelvinbridge and 170 m for the cluster south of Glasgow). Similarly, for Inverurie, the modified DBSCAN method used an epsilon value of 170 m to correctly identify a single cluster in the study area,

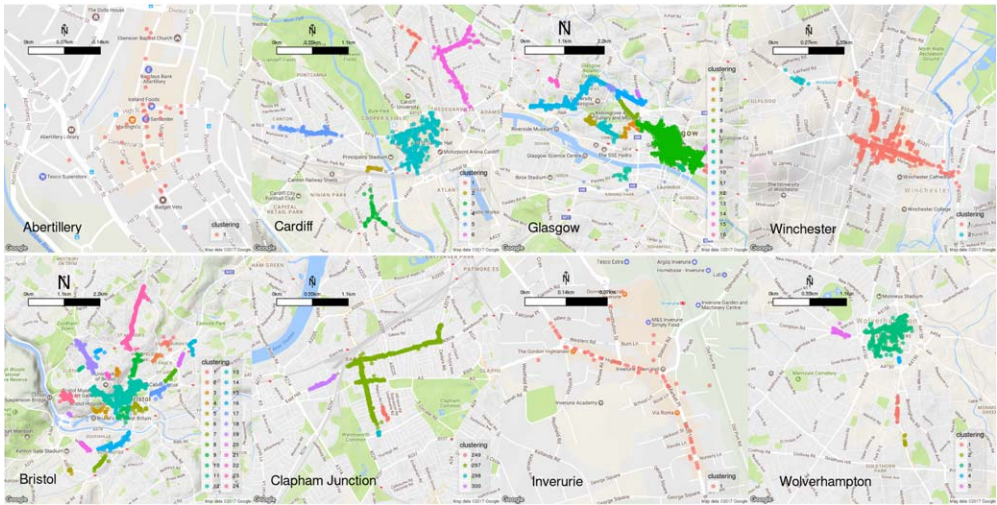


Figure 10. The clustering solutions produced by the modified DBSCAN clustering method for the eight case study sites.

compared to the two clusters identified by the traditional DBSCAN method when the global epsilon value of 107 m was used.

The results derived with this new method were compared to data supplied by the company Geolytix; which represent the only freely available and independently created national sample of contemporary retail center extents. They provide frequent updates of a data set of retail places across the United Kingdom, part of which (339 places) were licensed as open data in 2012. The Geolytix boundaries are produced using multiple variables (including the locations of retail units) (OpenData 2015) with information that was collected at least 3 years prior to the data that were used in our analysis. Additional causes of difference between the two data sets

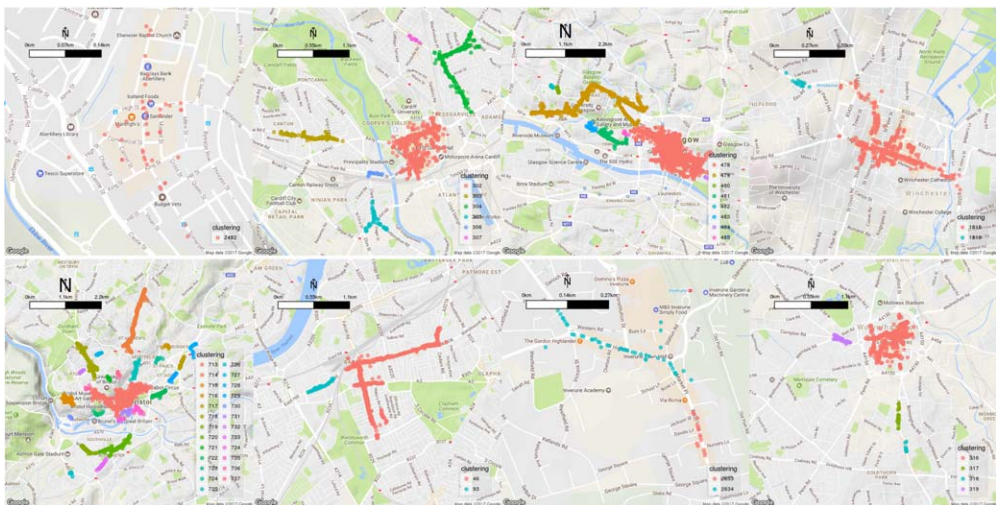


Figure 11. The clustering solutions produced by the DBSCAN clustering method for the eight case study sites.

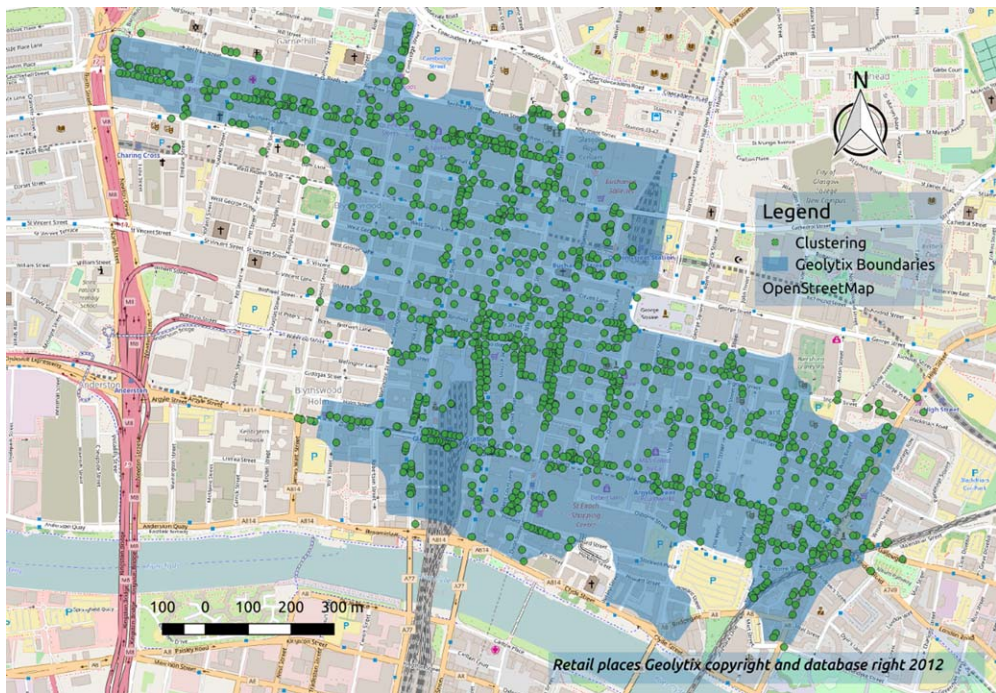


Figure 12. The retail unit locations that are members of the cluster of the city of Glasgow (green circles), overlaid on the Geolytix retail center boundaries.

might also include the different objectives and notion of what constitutes a retail center (Geolytix did not use a threshold of minimum 10 retail units), and only the boundary polygons from the clustered locations of the retail units were available. Given that the creation of similar polygon boundaries for our new results may result in an additional source of error, it was decided to compare the Geolytix boundaries against the retail unit locations and associated clusters. The comparison was based on two metrics, the n -ary relation between the two data sets and the proportion of points within the Geolytix polygons. The n -ary relation returns a score where the higher the number of clusters that had one-to-one relation with the clusters identified by Geolytix the better the relation.

Data pre-processing removed the major out of town retail parks from the Geolytix data set, which was followed by a spatial join of the Geolytix data set with the clustered retailer locations. There were 294 spatial intersections between the two data sets, out of which 244 were one-to-one. Summary values of the spatial distribution of the clustered locations within the Geolytix boundaries are shown in Table 3. On average (based on the median value) almost 90% of the clustered points were within the Geolytix boundaries.

Glasgow (Fig. 12) serves as an example where the two data sets mostly overlap, but also shows that the spatial extent of the clusters produced in this analysis was on average larger, which to some extent is related to Geolytix post-processing of boundaries to be constrained by the road network. Examples where the two data sets have significant differences include Bristol (Fig. 13) and London (Fig. 14).

Concerning Bristol, it can be seen that Geolytix split the city center into smaller clusters, of which only Broadmead was available as open data. However, the clustering solution for

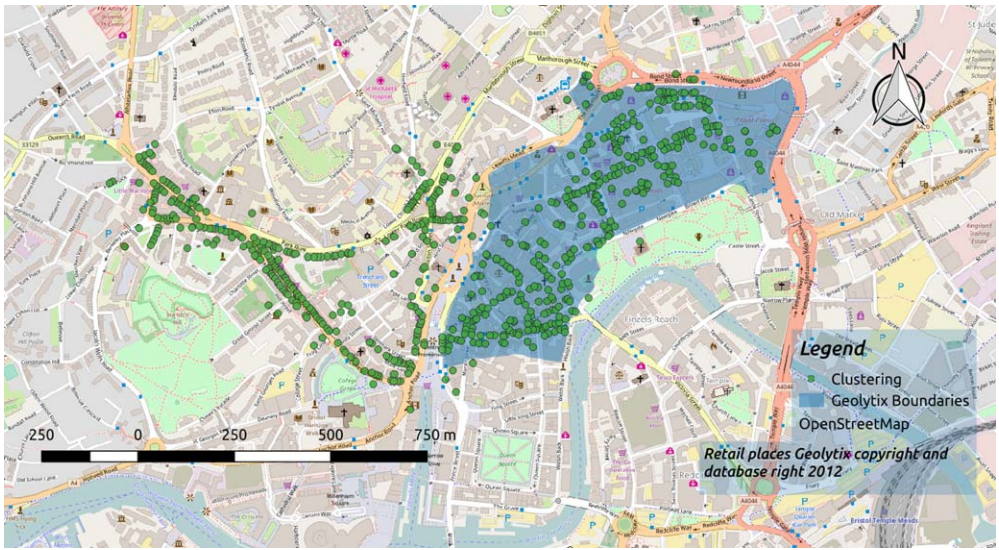


Figure 13. The retail unit locations that are members of the cluster of the city of Bristol (green circles), overlaid on the Geolytix retail center boundaries (only the area around the Broadmead shopping district was available as open data).

Bristol that was produced in this analysis was very similar to the one produced by the Bristol local authority and, thus, arguably more appropriate based on this local knowledge. Geolytix also split London into smaller clusters, seven of which were available for the area that was identified by the modified DBSCAN method as a single cluster. A possible reason for this difference could be that Geolytix used additional variables in their clustering method, which,

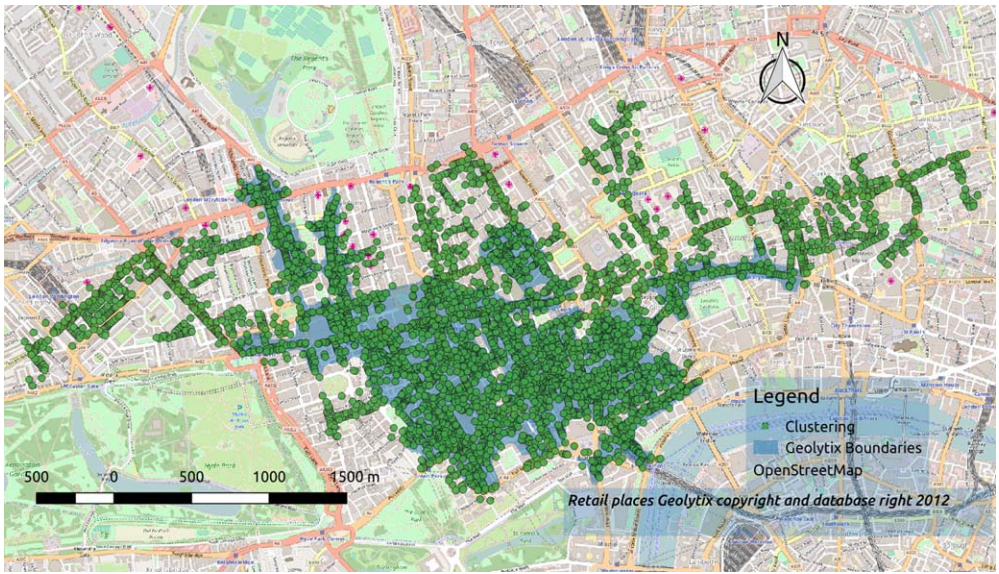


Figure 14. The retail unit locations that are members of the cluster of the city of London (green circles), overlaid on the Geolytix retail center boundaries.

Table 4. Summary Values Describing the Spatial Distribution of the Clustered Locations within the Geolytix Boundaries

Minimum	First quartile	Median	Mean	Third quartile	Maximum
0.68	63.97	89.81	73.99	95.99	100.00

particularly for London, would result in identifying clusters based on different retail activities rather than just retail density. Despite these mismatches that to some extent are related to different objectives and notions of what constitutes a retail center, it could be argued that the two clustering solutions largely overlap in the areas that were available by the open source Geolytix retail places, which provides evidence for the validity of the retail clusters that were produced in this work vis-à-vis competing methods (Table 4).

Conclusions

The objective of this analysis was to develop a clustering method that would facilitate the identification of retail agglomerations across a national extent and that could be updated over time. For this purpose, five of the most frequently used clustering methods were compared within eight representative locations across G.B. The DBSCAN method was selected on the basis that it provided the most accurate representation of those retail areas relative to formal definitions; it was faster to produce a clustering solution and also easier to calibrate optimized input parameter values.

However, to address a well-known issue that DBSCAN does not cope well in areas of varying densities, the DBSCAN method was adapted so that it could be iteratively applied within smaller more homogeneous sites that were created using a k-NN sparse graph representation of the retail locations. Each selected retail cluster was created by the DBSCAN algorithm with an epsilon value that was representative of the local point density. The clusters produced were comparable to those retail areas designated by the local authorities for the sample areas of study, and in some cases, were more accurate when compared to the traditional DBSCAN method. In addition, the identified clusters were in most areas similar in terms of spatial extent to those produced by the Geolytix company using alternative data set and methodology. It should be noted that even though the suggested method is more demanding in terms of computer resources compared to the traditional DBSCAN, it scales better as it could be applied in parallel for each subgraph.

Furthermore, the output of this analysis provides a better spatial coverage and option for automated update in comparison to the existing DCLG town center boundaries. Given that the DCLG boundaries were widely used by academics, local authorities and private organizations across the country it can be anticipated that these results will prove to be valuable for research and analysis.

With the developed methodology being open source (https://github.com/mpavlis/graph_dbscan), it will also be straightforward to update the retail boundaries on a regular basis, and potentially apply the suggested method within a context of historic data. Finally, given the variety in point density, size, and shape of the retail clusters in the data set it would be reasonable to assume that the methodology could be applicable with different data sets and for different international locations.

References

- Azzalini, A., and G. Menardi. (2014). "Clustering Via Nonparametric Density Estimation: The R Package pdf Cluster." *Journal of Statistical Software* 57(11), 1–26.
- Azzalini, A., and N. Torelli. (2007). "Clustering Via Nonparametric Density Estimation." *Statistics and Computing* 17, 71–80.
- BCAP. (2015). "Bristol Central Area Plan." Available at: <https://www.bristol.gov.uk/documents/20182/34540/BCAP%20Adopted%20March%202015%20-%20Policies%20Map%20-%20Web%20PDF.pdf/49f1d2b3-dda4-4ecf-8cf9-e20fe7b7c34c>
- Benjamin, J. D., G. D. Jud, and D. T. Winkler. (2000). "Retail Vacancy Rates: The Influence of National and Local Economic Conditions." *Journal of Real Estate Portfolio Management* 6(3), 249–58.
- Berry, B. J. L. (1967). *Geography of Market Centers and Retail Distribution*. Englewood Cliffs, NJ: Prentice-Hall.
- Campos, G. O., A. Zimek, J. Sander, R. J. G. B. Campello, B. Mícenkova, and E. Schubert. (2016). "On the Evaluation of Unsupervised Outlier Detection: Measures, Datasets and an Empirical Study." *Data Mining and Knowledge Discovery* 30(4), 891–927.
- Clauset, A., M. E. J. Newman, and C. Moore. (2004). "Finding Community Structure in Very Large Networks." Available at: <https://arxiv.org/pdf/cond-mat/0408187.pdf>
- Csardi, G., and T. Nepusz. (2006). "The igraph Software Package for Complex Network Research." *Inter-Journal, Complex Systems*, 1695. Available at: <http://www.necsi.edu/events/iccs6/papers/c1602a3c126ba822d0bc4293371c.pdf>
- DCLG. (2009). "Practice Guidance on Need, Impact and the Sequential Approach." Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/7781/towncentresguide.pdf
- Dearden, J., and A. Wilson. (2011). "A Framework for Exploring Urban Retail Discontinuities." *Geographical Analysis* 43(2), 172–87.
- Desgraupes, B. (2013). "Clustering Indices." Available at: <https://cran.r-project.org/web/packages/clusterCrit/vignettes/clusterCrit.pdf>
- Ester, M., H. P. Kriegel, J. Sander, and X. Xiaowei. (1996). "A Density-Based Algorithm for Discovering Clusters in Large Spatial Databases with Noise." Available at: <https://www.aaai.org/Papers/KDD/1996/KDD96-037.pdf>
- Everitt, B. S., S. Landau, M. Leese, and D. Stahl. (2011). *Cluster Analysis*, 5th ed. Chichester, U.K.: Wiley.
- Gan, G., C. Ma, and J. Wu. (2007). "Data Clustering. Theory, Algorithms and Applications." *ASA-SIAM Series on Statistics and Applied Probability*. Alexandria, VA: SIAM, Philadelphia, ASA.
- Halkidi, M., and M. Vazirgiannis. (2002). "Clustering Validity Assessment Using Multi-Representatives". Available at: http://lpis.csd.auth.gr/setn02/poster_papers/237.pdf
- Hornik, K. (2007). "A CLUE for CLUster Ensembles." Available at: <https://cran.r-project.org/web/packages/clue/vignettes/clue.pdf>
- Karypis, G., E. Han, and V. Kumar. (1999). "Chameleon: Hierarchical Clustering Using Dynamic Modelling." *IEEE Computer* 32(8), 68–75.
- Liu, Y., Z. Li, H. Xiong, X. Gao, and J. Wu. (2010). "Understanding of Internal Clustering Validation Measures". Available at: <http://datamining.rutgers.edu/publication/internalmeasures.pdf>
- Lloyd, S. P. (1982). "Least Squares Quantization in PCM." *IEEE Transactions on Information Theory* 28, 128–37.
- Mackness, W. A., and O. Z. Chaudhry. (2011). "Automatic Classification of Retail Spaces from a Large Scale Topographic Database." *Transaction in GIS* 15(3), 291–307.
- Newing, A., G. P. Clarke, and M. Clarke. (2015). "Developing and Applying a Disaggregated Retail Location Model with Extended Retail Demand Estimations." *Geographical Analysis* 47, 219–39.
- Newman, M. E. J. (2004). "Fast Algorithm for Detecting Community Structure in Networks." Available at: <http://arxiv.org/pdf/cond-mat/0309508.pdf>
- NPPF. (2012). "National Planning Policy Framework." Available at: <http://planningguidance.communities.gov.uk/blog/policy/achieving-sustainable-development/annex-2-glossary/> (accessed 08/21/2017)
- OpenData. (2015). Available at: <http://opendata-aha.net/retail-places-new-release-for-2015/> (accessed 05/09/2016)

- Pons, P., and M. Latapy. (2005). "Computing Communities in Large Networks Using Random Walks." Available at: <http://arxiv.org/pdf/physics/0512106v1.pdf>
- Rogstad, L., and M. Dysterud. (1996). "Land Use Statistics for Urban Agglomerations: Development of a Method Based on Administrative Records and the Use of Geographical Information Systems." *Statistical Journal of the United Nations Economic Commission for Europe* 13(4), 413–17.
- Scharl, T., and F. Leisch. (2006). "The Stochastic QT-Clust Algorithm: Evaluation of Stability and Variance on Time-Course Microarray Data." Available at: <http://www.statistik.lmu.de/~leisch/papers/Scharl+Leisch-2006.pdf>
- Singleton, A. D., L. Dolega, D. Riddlesden, and P. Longley. (2016). "Measuring the Spatial Vulnerability of Retail Centres to Online Consumption Through a Framework of e-Resilience." *Geoforum* 69, 5–18.
- Teller, C., and T. Reutterer. (2008). "The Evolving Concept of Retail Attractiveness: What Makes Retail Agglomerations Attractive When Customers Shop at Them?" *Journal of Retailing and Consumer Services* 15, 127–43.
- Thurstain-Goodwin, M., and D. Unwin. (2000). "Defining and Delineating the Central Areas of Towns for Statistical Monitoring Using Continuous Surface Representations." *Transactions on GIS* 4(4), 305–17.
- Wrigley, N., and D. Lambiri. (2015). "British High Streets: From Crisis to Recovery? A Comprehensive Review of the Evidence." Available at: <http://thegreatbritishhighstreet.co.uk/pdf/GBHS-British-High-Streets-Crisis-to-Recovery.pdf>
- Xu, X., M. Ester, H. P. Kriegel, J. Sander. (1998). "A Distribution-Based Clustering Algorithm for Mining in Large Spatial Databases." In *Proceedings of the 14th International Conference on Data Engineering*, 324–31, University of Munich Oettingenstr. 67 D-80538 Munchen.