Spatial Statistics for Commercial Applications

An ESRI® White Paper • April 2005

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Spatial Statistics for Commercial Applications

Introduction

Commercial organizations have used geographic information system (GIS) technology for various applications ranging from site selection to business continuity plans (BCP). These applications have allowed analysts to better understand their markets by incorporating geography into their traditional work flows. GIS enables analysts to ask a different set of questions than they typically have been able to by relying solely on databases, spreadsheets, and traditional business intelligence packages.

In a traditional database, pieces of information (tables) are linked to one another by unique identifiers that allow analysts to traverse these tables and pull out the required information. While this capability (joining or relating to external tables) is certainly available in a GIS, the real power is derived from the fact that a GIS does not always need unique identifiers to tie disparate sets of data together. Since all GIS data uses a real-world coordinate system, one can add seemingly unconnected sets of information to a GIS in layers and find new relationships and interdependencies.

Organizations have used GIS tools geared for commercial applications, such as retail, real estate, and restaurants, for quite some time. ESRI® ArcGIS® Business Analyst has specific tools that enable these users to ask geographic questions of their customer and store databases. ArcGIS Business Analyst also comes bundled with demographic data, so that analysts can create demographic and market basket reports from their analysis. Business Analyst software's toolset makes it easy to perform the following common tasks:

- Create customer-based or store trade areas.
- Perform customer or store prospecting.
- Find a location similar to that of your best store.
- Perform drive-time analysis.
- Create gravity models to forecast potential sales at new stores.

In addition to these types of analyses, many businesses have been concerned with making sure that they can survive major disruptions. These disruptions can be attributed to a number of different factors such as

- Power outages
- Flood (internal pipe burst)
- Weather related

- Fire
- Terrorism/Crime
- Transportation problems

It is well to remember that one in five businesses do experience a major disruption each year. Because of this, more and more businesses have started preparing for possible disruptions by creating a business continuity plan. Many aspects of BCPs have a geographic component, and GIS makes it easy for responders to get a quick snapshot of where assets and employees are located in dashboard-style applications. It is also well suited for analysts to model what-if scenarios that capture the infrastructure, business processes, and locations of an organization. Having a BCP in place enables businesses to mitigate some of the risks of disruptions such as health and safety liabilities, loss of productivity from downtime, loss of work to competitor, failures within the supply chain, higher insurance, and so forth.

GIS is uniquely positioned to help businesses develop BCPs and address the following issues:

- Facilities management
- Employee (and family) management
- Incident mapping
- Weather mapping
- Office relocation
- Evacuation
- Threat assessment
- Supply chain assessment

ArcGIS 9 introduced a new geoprocessing framework allowing users to capture their work flows and automate common tasks as well as a number of new geoprocessing tools. One set of new tools that was introduced is a group of statistical functions especially designed to work with spatial data. These functions allow analysts to compare features and geographic distributions and to model geographic relationships. This paper is intended to be an introduction to how these tools may be used for business analysis for both retail type problem solving and as a BCP tool.

The Use of Spatial Statistics in Retail Applications

Analysts have used GIS in retail applications to answer fundamental, business critical questions such as

- Where are my best customers?
- Where can I find more customers?
- Where is my competition?
- Where should I locate a new store?
- Who is the typical person who buys my product?

These questions have been answered in a number of ways with the use of basic techniques such as geocoding existing customers and stores and looking at the distribution. One simple example of this is to plot the distance between customers against the amount of money each customer spends at a store. A GIS enables analysts to

both calculate the distance to stores from each customer as well as create the scatter plot to represent this information.

Figure 1 shows that the transaction amount tends to drop off with distance, with several exceptions. The user can, of course, click on an individual point on the graph and see where this is located on the map as well as see the attribute information such as transaction amount, date of purchase, and so on.

Figure 1: Scatter Plot of Transaction Amount Versus Distance to Store

Once analysts have a better understanding of the data, they can use other tools of the GIS such as ArcGIS Business Analyst. Business Analyst allows users to perform tasks common to retail clients through an easy-to-use, wizard-driven interface. Business Analyst provides the functionality to perform typical tasks such as analyzing trade area markets and competition, finding the best location for a new store, and target marketing. In addition to the wizard-based interface, Business Analyst includes an extensive library of data including demographic data; a national business database; shopping center data; household consumer data; segmentation data; and a nationwide, routable street network dataset.

An analyst may want to take a deeper look into the data to better understand the distribution of customers and to be able to predict where more customers can be found.

Using the new spatial statistics in conjunction with the tools provided by the Business Analyst extension creates a powerful framework in which to pose a new set of questions and, consequently, derive new answers.

Analyzing Patterns and Clusters

Various retail applications can use pattern and cluster tools ranging from looking at customer and sales distributions to investigating proposed customer prospecting sites. Tools that fall into this category evaluate whether the features or attributes in a dataset tend to be clustered, dispersed, or random within a region as well as identify statistically significant outliers and clusters of hot spots and cold spots.

When a new set of data is presented, such as the output of a customer prospecting function, the analyst must begin to understand the structure of the data before making further decisions. Customer prospecting tools have been used for quite some time with GIS and are available within the Business Analyst toolset. The customer prospecting wizard enables users to search for areas that contain a certain type of customer at various levels of geography. The user can query the data to find the most profitable customers and begin to look for the demographic characteristics that differentiate these customers from the average customer such as income, percent homeownership, and so on. The output from the customer prospecting tool is a new layer showing the areas that match the input criteria (see Figure 2). This data layer is new to the analyst, and it can be useful to investigate the data more closely to gain a better understanding of it.

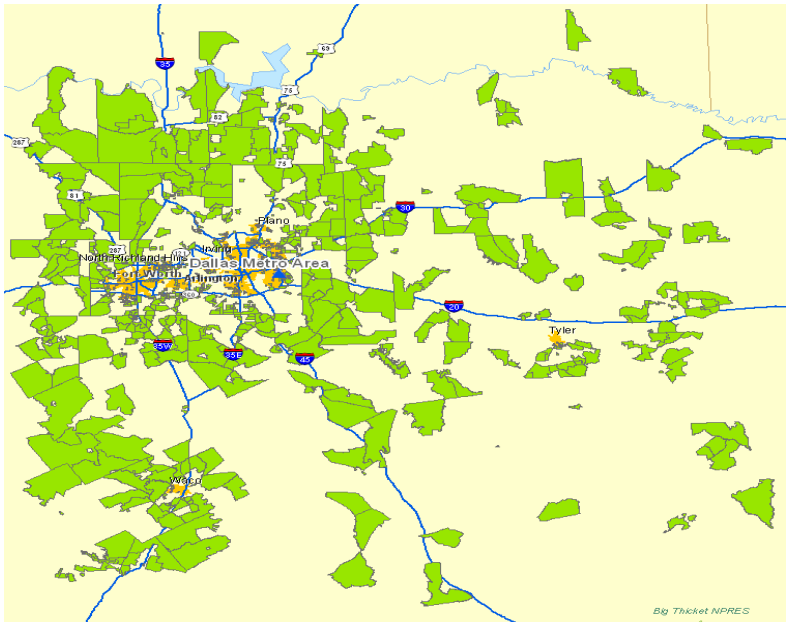

Figure 2: The results of a customer prospecting analysis. The areas in green represent the block groups containing the desired demographics.

When a new set of data is placed on a map, it is beneficial to use some statistical techniques to identify if the data tends to be clustered or dispersed, both in terms of the geometry and the attribute value of interest. The new spatial statistics provide two such tools: Average Nearest Neighbor and High/Low Clustering (Getis-Ord General G).

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Average Nearest Neighbor Tool

The Average Nearest Neighbor tool evaluates whether or not there is geometric clustering in the data. That is, if the data on the map tends to be spatially clustered. This tool does not take the attribute values of the data into account. Running the Average Nearest Neighbor tool on the customer prospecting dataset shows that the data is indeed clustered and that the observed pattern is statistically significant. Figure 3 shows the output from this tool. The tool works by measuring the distance between each feature and its nearest neighbor. It then calculates the mean for all these distances and compares it to a hypothetical random distribution. If the mean distance is greater than the mean for the hypothetical random distribution, the data is considered to be dispersed. If the opposite is true, the data is considered to be clustered. The Z Score indicates the odds of the observed pattern being the result of chance. The tool summarizes this information in an easy-to-understand sentence: There is less than 1 percent likelihood that this dispersed pattern could be the result of random chance. We can therefore conclude that the data is clustered, but we are unable to say if the values in the data are clustered or not. For that we need to use another tool. If the data is clustered, further analysis can be performed to determine the best location for a new store. If the data is dispersed, it may indicate that several stores will be required to capture all potential customers, or that a marketing effort is needed to bring people to the stores where the most profitable customers exist but not in significant enough numbers to warrant opening a new store.

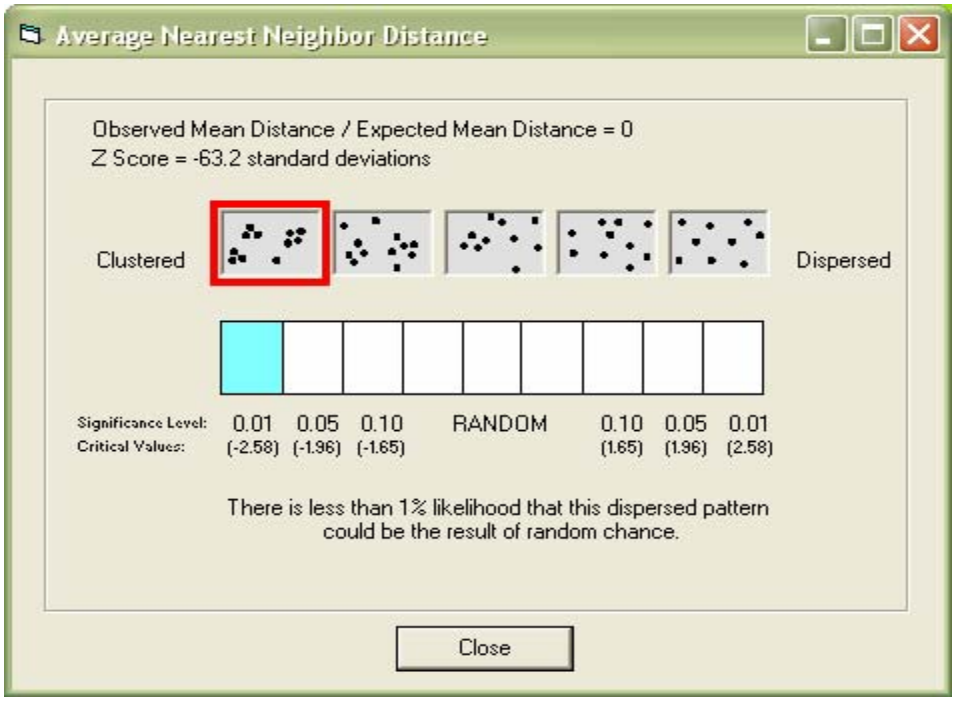

Figure 3: The Average Nearest Neighbor tool shows the degree of clustering in the data as well as whether this is statistically significant.

High/Low Clustering (Getis-Ord General G) Tool

The High/Low Clustering tool indicates if either high or low values tend to be clustered within the data. In the example above, when the customer prospecting tool ran, two input demographics were used to find untapped areas of the most profitable customers: average income and percent household ownership. These two variables seemed to be indicators of where the user could find the most profitable customers. To use the

High/Low Clustering tool, the user first has to combine these two variables into a single field. To do this, the user reclassifies them on a scale of one to 10, where one is the least favorable and 10 is the most favorable, and adds them together to form one measure. This new measure becomes the input field for the High/Low Clustering tool. Figure 4 shows the output from this tool. The higher the General G value is, the more clustered the high values are in the data. The lower the General G value is, the more clustered the low values are in the data. The Z Score shows the strength of the association. If the Z Score is very high (or very low), there is a strong association. If the Z Score is near 0, it indicates that there is no apparent clustering within the data. Again, the tool provides this information in an easy-to-understand sentence: There is a less than 5 percent likelihood that the clustering of high values is the result of random chance. We can therefore conclude that high values tend to cluster together in this dataset. This means that we now need to identify where this clustering occurs to identify potential locations for new stores. If low values had been clustered, it would indicate that there are still opportunities in this area but that the most profitable potential customers tend not to be as clustered. It is well to remember, however, that we are starting with a fairly high-quality list of potential sites, so this designation is relative.

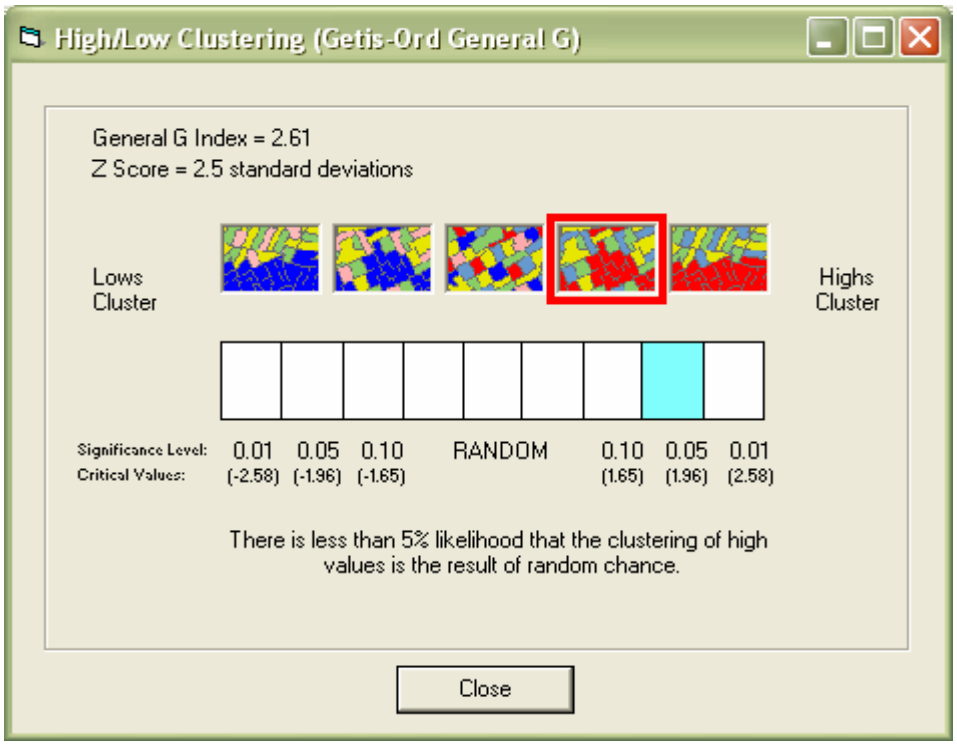

Figure 4: The High/Low Clustering tool shows whether high or low values tend to be clustered or random.

Now that the analyst has learned a little more about the distribution of the customer prospecting data, other tools may be used to identify the location of hot spots of the most profitable potential customer sites. To accomplish this, there is a hot spot tool called the Hot Spot Analysis (Getis-Ord Gi*) tool.

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Hot Spot Analysis (Getis-Ord Gi*) Tool

The Hot Spot Analysis tool is used to find the location of spatial clusters of high and low attribute values. This will show areas where higher than average values tend to be found near each other and where lower than average values tend to be found near each other. For the customer prospecting output data, this will give us potential locations for new stores. This tool can be run in two modes: report back the statistics from the analysis or create a new, formatted layer file that can be added to a map. This output graphically shows the locations of the hot and cold spots (see Figure 5). This shows quite a different picture from the original plot of customer prospecting locations (see Figure 2). You will notice that hot spots tend to be located on the outskirts of the two cities in the map, Dallas and Fort Worth.

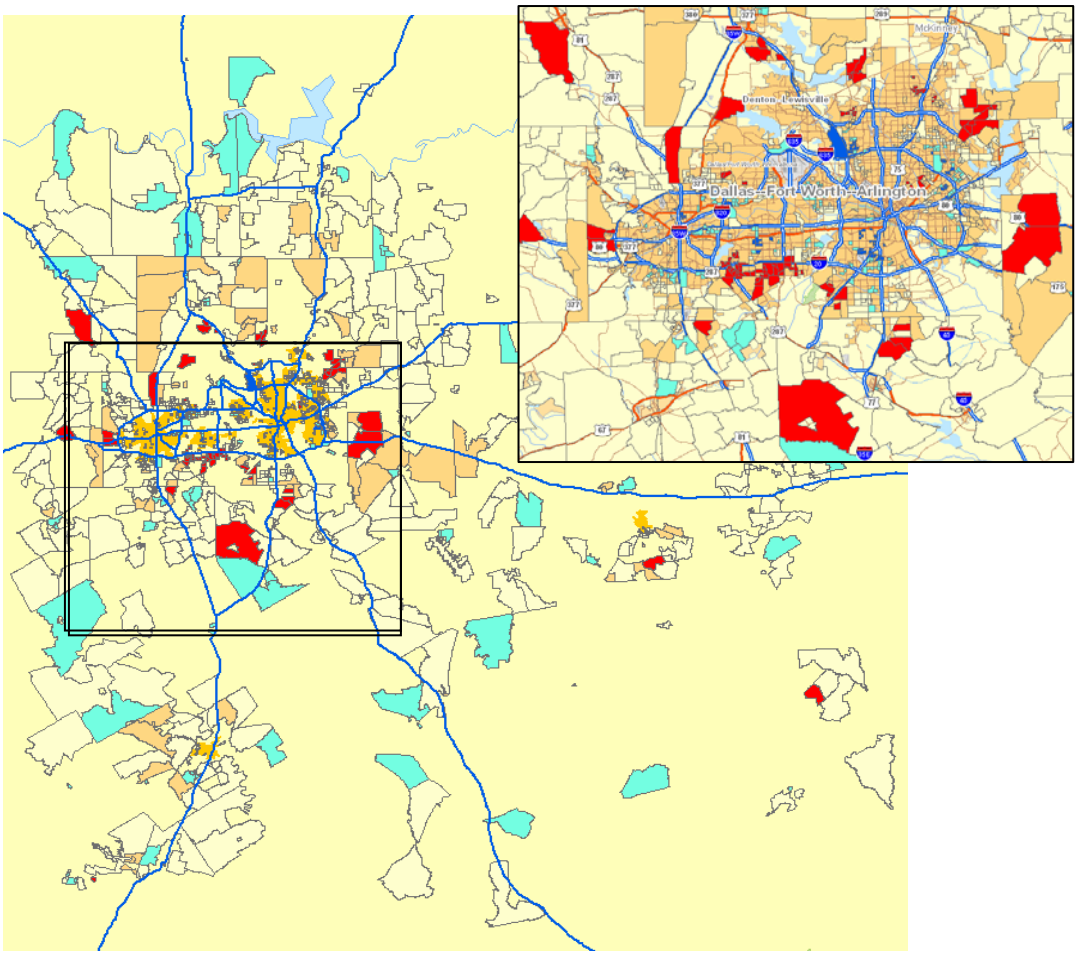

Figure 5: The Hot Spot Analysis tool for customer processing data. The areas in red represent statistically significant hot spots of the most desirable potential customers. Dark blue indicates statistically significant cold spots.

There are many uses for the Hot Spot Analysis tool beyond our customer prospecting example. One fundamental function of retail analysts is to understand the distribution of customers and sales for a given store. The analyst is looking for clusters of customers who spend more money than the average customer. It should be noted that finding clusters of customers who are spending less than the average customer could be just as useful. Simply placing the customers on a map through geocoding will give an analyst

more information than is possible without a GIS (see Figure 6). Even in this early stage, we can see some apparent clustering of the data. If the analyst then changes the symbology of the customer so that the size of the point shows the amount of money the customer has spent at a store, the map immediately tells more of a story (see Figure 7). The apparent clusters that we now see provide us with more information; however, even if the data was totally random, we would expect to see some sort of pattern.

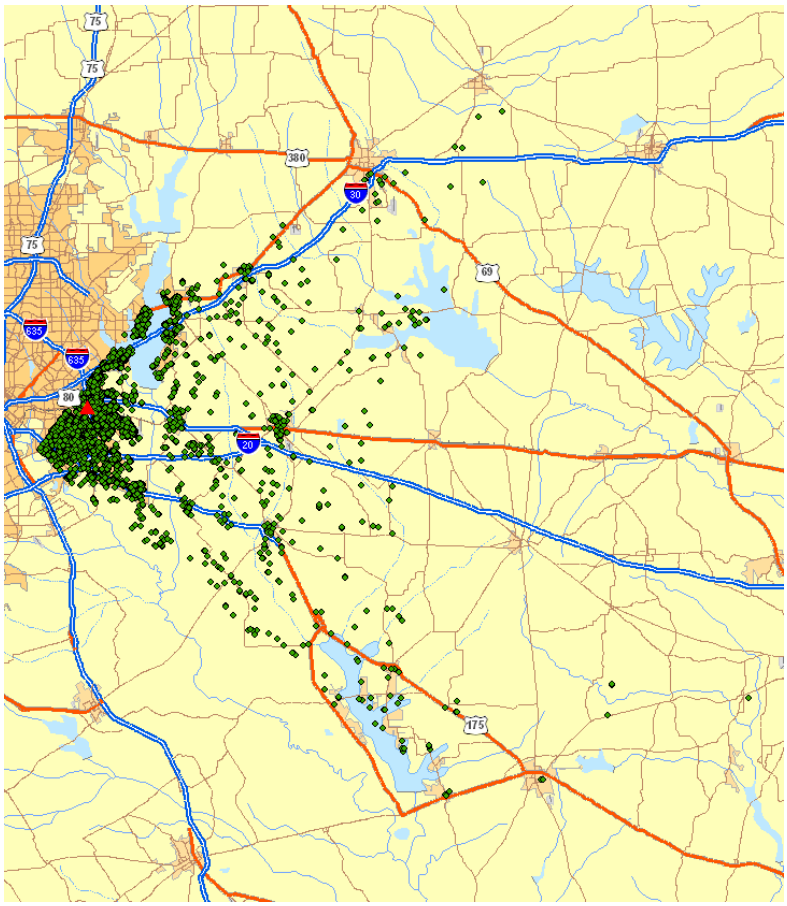

Figure 6: Location of Customers

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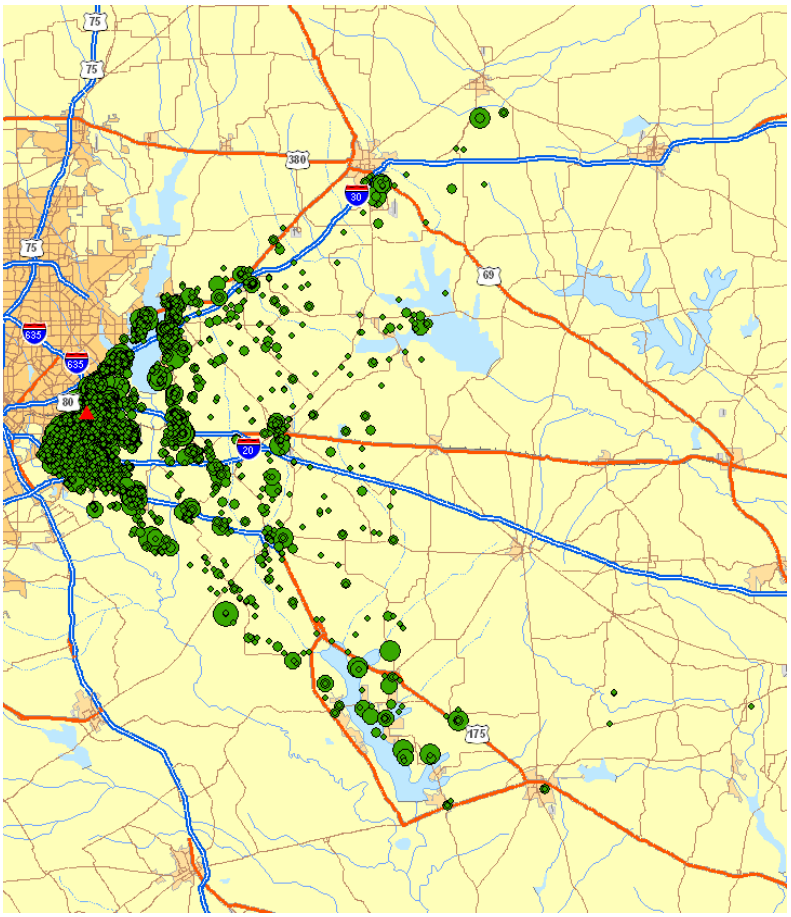

Figure 7: Customers are symbolized by the amount of money spent at the store.

The Hot Spot Analysis tool allows analysts to test if those patterns are statistically significant. The goal is to have a map that shows where customers are spending more than the average and less than the average. This will enable analysts to look closer at those specific locations and see if there is a demographic (or other) reason for this pattern. This information could be used in a number of different ways. Perhaps the cold spots are more interesting since they enable managers to see areas that are underperforming. This may indicate areas that need to be targeted by a marketing campaign. If more detailed transaction information is available, the analyst could look at the types of goods being bought by those customers and begin to tie those to demographic characteristics. It may also be interesting to use the hot spots for customer prospecting. Usually, when one performs customer prospecting, analysts select the customers who are spending the most amount of money at a store and look for demographically similar areas. The analyst could use the hot spots to determine the demographics to search for. This will provide a slightly different picture from the usual method. Figure 8 shows the results of running the Hot Spot Analysis tool on this dataset. In this figure, only the hot spot results are shown (as opposed to both the hot and cold spots) overlaid on the thematically mapped customer transaction data.

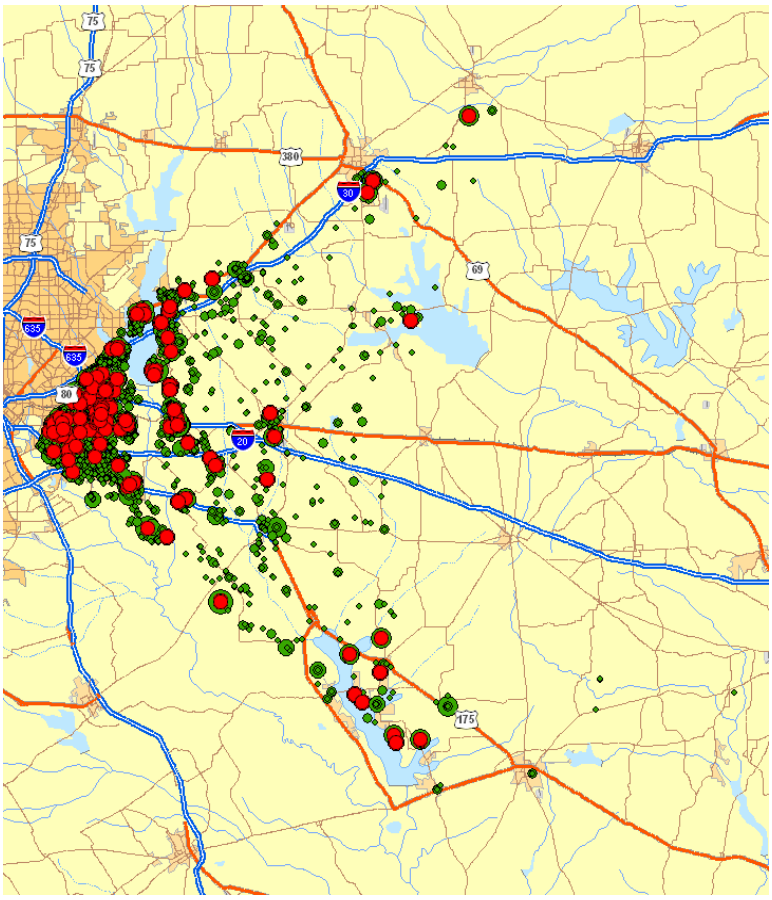

Figure 8: Transaction hot spots are overlaid on thematically mapped transaction data.

When working with tools such as the High/Low Clustering and Hot Spot Analysis tools, one of the inputs is a distance band. When these tools look at each data point, they also take into account the surrounding features. The number of features taken into account is determined by the distance band selected. The distance chosen by the analyst can affect dramatically the output of the analysis. The distance to use may be based on how far customers are willing to travel to get to a store. Another way to determine an appropriate distance band is to use the Spatial Autocorrelation (Moran's I) tool.

Spatial Autocorrelation (Moran's I) Tool

The Spatial Autocorrelation tool provides a measure of feature similarity based on both the feature location and an associated attribute value. It measures whether or not a given set of features is clustered, dispersed, or random. To find an appropriate distance band, run the Spatial Autocorrelation tool specifying different distances each time. Start by making sure that the initial distance is large enough so that every point has at least one neighbor. Jot down the output Z Score. As the distance increases, keep noting the Z Score. When the Z Score reaches a maximum, select a distance between the current distance and the previous distance. It is important to remember that there may be several distances that display peaks in the Z Score. This is due to the fact that there can be different spatial relationships among the data at different scales. One pattern may appear at a small scale and another quite different pattern may appear at a larger scale.

Experimenting with the data will result in a better understanding of these scale effects and will enable the analyst to choose an appropriate distance band.

Viewing hot spots and cold spots can provide a unique view of customer and sales distributions, but it may also be of use in identifying outliers within the data. This can help analysts identify anomalies in their data that may point to an untapped market, or it may help identify customers who should be omitted from further analysis such as customer prospecting. Before an outlier is omitted, however, further investigation should be performed to make sure that a valid, but unusual, data point is not left out accidentally. In a recent investigation of customer data, a customer location was identified as an outlier both in terms of the distance from the store and in the transaction amount. Initially, this was highlighted by creating a scatter plot (similar to Figure 1) with the transaction amount on the y-axis and the distance to store on the x-axis. This was statistically verified by running the Cluster and Outlier Analysis (Anselin Local Moran's I) tool. Upon further investigation, it was shown that the customer only visited the store one time in the last 12 months, on December 24 with two rather large transactions. It is probably fair to say that this customer is not a good indicator of the average high-quality customer. Probably, this customer was traveling and happened to be in the vicinity of the store and most likely only entered the store because he/she needed to pick up some last minute holiday gifts. This is a case in which we can feel relatively comfortable discarding the record from further analysis.

Cluster and Outlier Analysis (Anselin Local Moran's I) Tool

The Cluster and Outlier Analysis tool enables analysts to identify areas with features that have values of similar magnitude and areas with very heterogeneous values. The output gives the analyst a snapshot of the diversity of values within an area.

Measuring Geographic Distributions

Another useful set of tools can be described generally as measuring geographic distributions. These tools enable analysts to derive characteristics about data distributions such as central features, compactness, and orientation. The Directional Distribution (Standard Error Ellipse) tool can be used to gain a better understanding about how sales change over time.

Directional Distribution (Standard Error Ellipse) Tool

This tool measures whether or not a dataset exhibits a directional trend. There are many factors that can influence the directional trend in a dataset such as natural barriers (lakes, mountains, etc.); competition; and, quite commonly, the underlying street network. There can also be temporal reasons for the variations. There are typically shifts in the directional influence of the customers over the course of an entire year. Figure 9 shows the standard error ellipse for all the data for an entire year. The calculation has been weighted by the transaction amounts, so it is not simply a representation of the geometry but also of the attribute values. The more elongated the ellipse, the stronger the directional influence within the data. This same technique can be repeated for different times of the year. Figure 10 shows how the directional influence changes at different times in the year. The first map shows the directional distribution for December, followed by the directional distribution for January and February. Having this level of information available for analysis allows analysts to review seasonal marketing campaigns. This type of data is particularly useful when the data is automated over time. The ArcGIS Tracking Analyst extension has a playback manager that will animate temporal data, enabling users to see change over time.

Other available tools, similar to the Directional Distribution tool, include the Standard Distance tool, which quantifies how compact the data is, and the Mean Center tool, which can calculate the weighted mean center of a distribution. Some of these tools can be used for specific applications. For example, the Central Feature tool allows analysts to select the most central feature in a dataset. This tool is especially useful for finding the most conveniently located warehouse or restocking center.

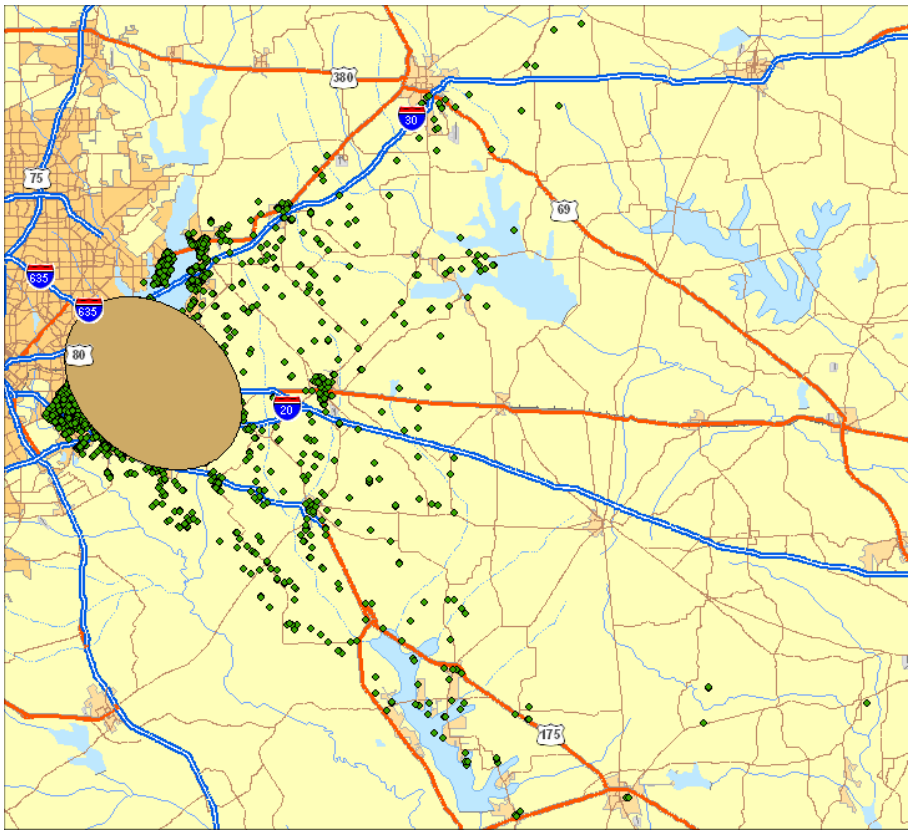

Figure 9: The directional distribution ellipse for the entire year is shown, weighted by customer transaction amount.

Figure 10: The directional distribution ellipses for several months are shown—December, January, and February.

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The Use of Spatial Statistics in Business Continuity Plans

The Business Continuity Institute defines Business Continuity Management as a "holistic management process that identifies potential impacts that threaten an organization and provides a framework for building resilience with the capacity for an effective response that safeguards the interests of key stakeholders, reputation, brand and value creating activities." Even the simplest of GIS applications adds value to standard BCPs. A fundamental part of creating a BCP is assessing where all of a company's assets are located including buildings and employees. Simply geocoding these assets allows BCP managers to monitor these assets in relation to potential disruptions. By integrating geography into their human resources and real estate practices, companies can look for threats within some proximity to assets; assess the impact of incidents on the business; work through what-if scenarios; and identify essential tasks, personnel, and facilities. GIS is particularly well suited to this type of application because of its inherent ability to integrate disparate sources of data from areas such as customer databases, human resources, and other external data. Executive dashboard applications can also be built allowing managers to get a high-level overview of situations in an easy-to-navigate interface. All of this effort is directed to understanding what needs to be done to reestablish critical business functions in the event of a disruption. This section of the paper will highlight a few of the countless uses of GIS and spatial statistics in BCPs.

Relocation

Any BCP must address the relocation of personnel, operations, and assets. In some industries, such as financial services, there are specific rules that govern what must be included in a BCP. For instance, New York Stock Exchange Rule 446 has a provision mandating that companies have a plan for relocation. In essence, this comes down to site selection. Analysts have employed the unique capabilities of GIS to provide an additional resource for site selection in many disciplines ranging from construction and environmental protection to finding an optimal location for a new store.

There are several factors BCP analysts are interested in that are usually not considered in traditional site selection applications. BCP analysts are particularly interested in mitigating risks, and so, in addition to the usual questions that are asked in such an analysis, they have to address potential threats such as proximity to terrorism targets. Since the relocation plan is typically a temporary one, they also have to look at where their employees are located, which employees are the most critical from a day-to-day operations perspective, and how they would get to work, given a temporary relocation.

One of the new spatial statistics tools is particularly well suited for this—the Mean Center tool. In this scenario, the analyst can identify the key personnel in an organization and place a weight value on each person, according to how critical he/she is to the operation. The analyst can then use the Mean Center tool to find the optimal location to relocate based solely on how convenient it is for the most critical employees. This is, of course, not the only factor that needs to be considered. There is a host of additional inputs that should be used for such an analysis. The new geoprocessing framework allows analysts to string functions together in a visual modeling environment called ModelBuilder™. This core component simplifies the process of creating complex models to answer key questions. In the example above, a model was created to take several factors into account: proximity to key employees, major roads, and existing customers. All these factors were evaluated, then compared to a layer containing available listings. The end result was a list of potential locations that met the criteria. Figure 11 shows the model that was used in this application.

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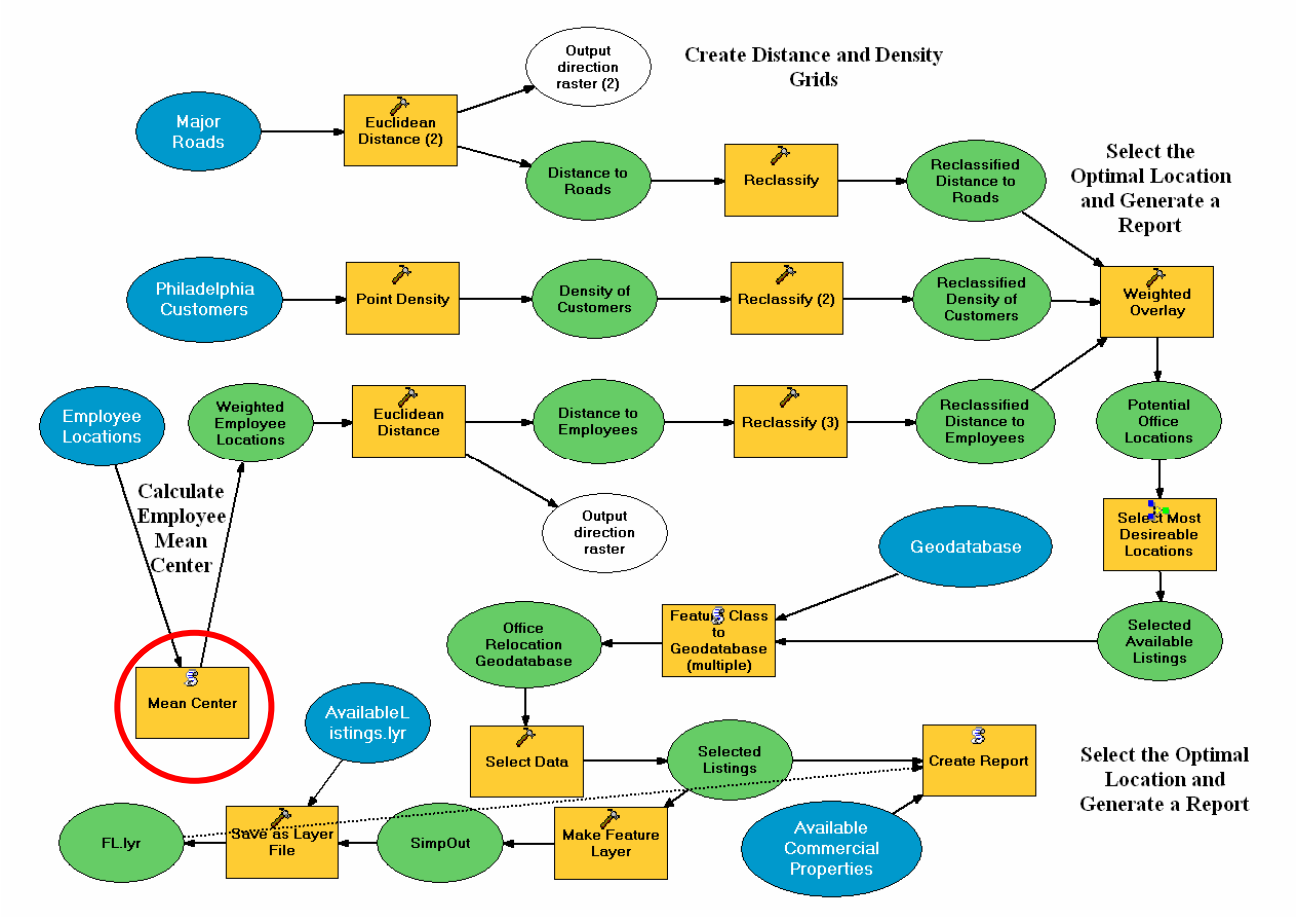

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Available Commercial Properties

Building Type	Rent per Sq Ft per Year	Available Space	Stories	Landlord	Link
Class B Office	$ 16	8,100	3	Trinity Capital Advisors	http://localhost/imagesOffice/2.
Class B Office	$ 16	10,035	3	Liberty Property Trust	http://localhost/imagesOffice/3.
Class A Office	$ 17	30,000	3	NAI Geis Realty Group Inc.	http://localhost/imagesOffice/5.

Figure 11: A site location model uses the Mean Center tool to identify locations convenient to critical employees, and the resulting report shows available commercial properties.

The model does several interesting things: not only does it use the Mean Center tool (highlighted with a red circle) to find the weighted mean center for critical employees, but it also creates a density surface of the current customers and a surface representing the distance to major roads. These layers are then combined using the ArcGIS Spatial Analyst extension, giving the proximity to critical employees more importance than the other inputs. The end result of the model is a map and a report that lists the potential properties with links to images of the buildings.

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Evacuation Meeting Point

Another example of using spatial statistics for BCPs is looking at individual building employee evacuation meeting points. Most of the time, businesses would prefer that employees stay inside a building during an emergency until the situation is fully understood; however, in some cases, a full evacuation is required. This can be a fairly simple task if the business is located in an office park, but if the office is located in a densely populated city such as New York, this poses a logistical problem. If the emergency is isolated to the individual building, it is a little easier to manage, but if the emergency affects the surrounding buildings as well, the plan must take into account the neighborhood around the building.

When companies evacuate buildings, they typically have a location where they will regroup and decide what needs to be done next. The question becomes, where should this meeting point be located? There are several factors that need to be considered such as the surrounding population, how far away from the building can people get to with ease (given that some people may have disabilities, for example), and are there open spaces that can be utilized? All these questions are geographic in nature. Figure 12 shows a simple model that uses the Hot/Cold Spot Analysis tool.

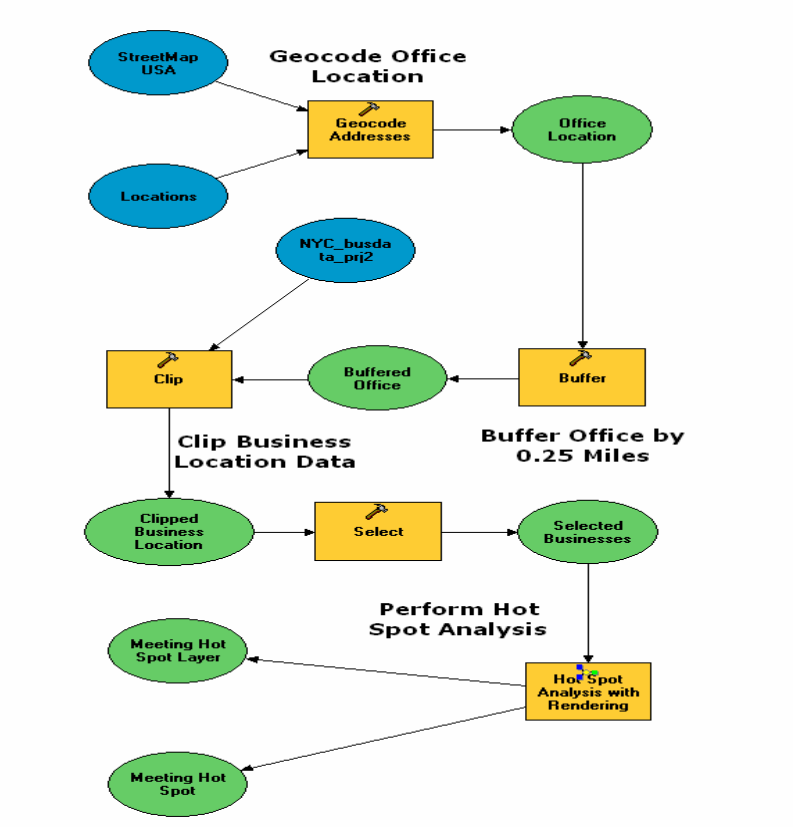

Figure 12: A meeting point model uses the Hot/Cold Spot Analysis tool to find statistically significant lower employee density areas to meet.

This model geocodes the address of the building in question then buffers that location by one-quarter mile (assuming that this is a reasonable distance to walk for everyone in the company). It then clips a business location dataset. This dataset is available from ESRI and contains the number of employees at business locations and is representative of daytime population. Using this dataset, the model then runs the Hot/Cold Spot Analysis tool to find statistically significant hot and cold spots of building employees. In this case, the analyst would be interested in identifying the cold spots since those are the locations where there are fewer people. Figure 13 shows the results of the analysis.

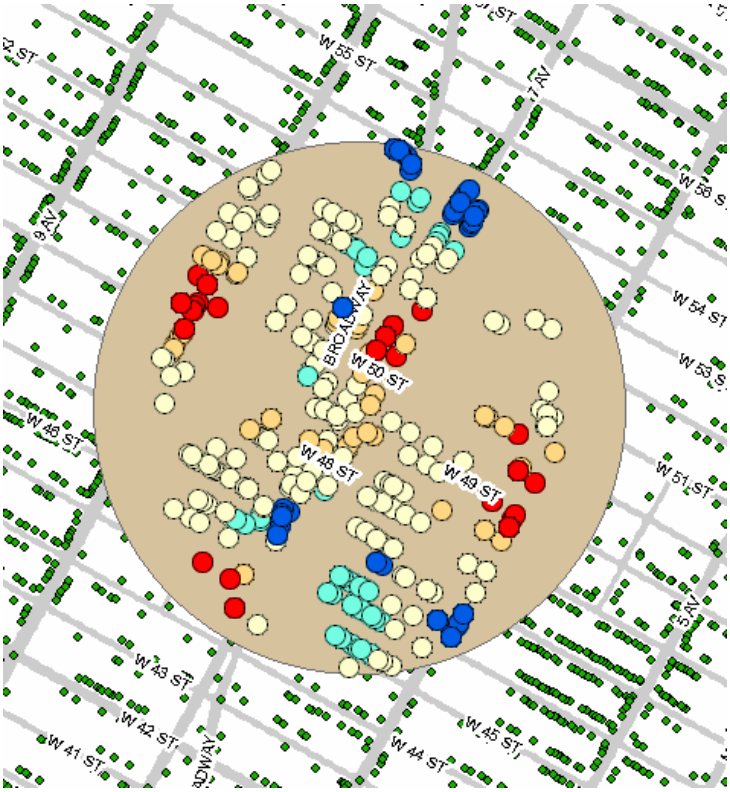

Figure 13: Potential evacuation meeting points within one-quarter mile of the selected business are shown.

The dark blue points are areas where there are statistically significant cold spots of employees. To more clearly see the areas that these points represent, it can be useful to create a continuous surface. Using ArcGIS Spatial Analyst, a surface reveals more generalized areas that represent cold spots in the data (the dark blue areas in Figure 14). These areas have been identified as being potential sites for meeting points but, of course, more information is required, such as looking at orthophotos of the area, before a final location is selected.

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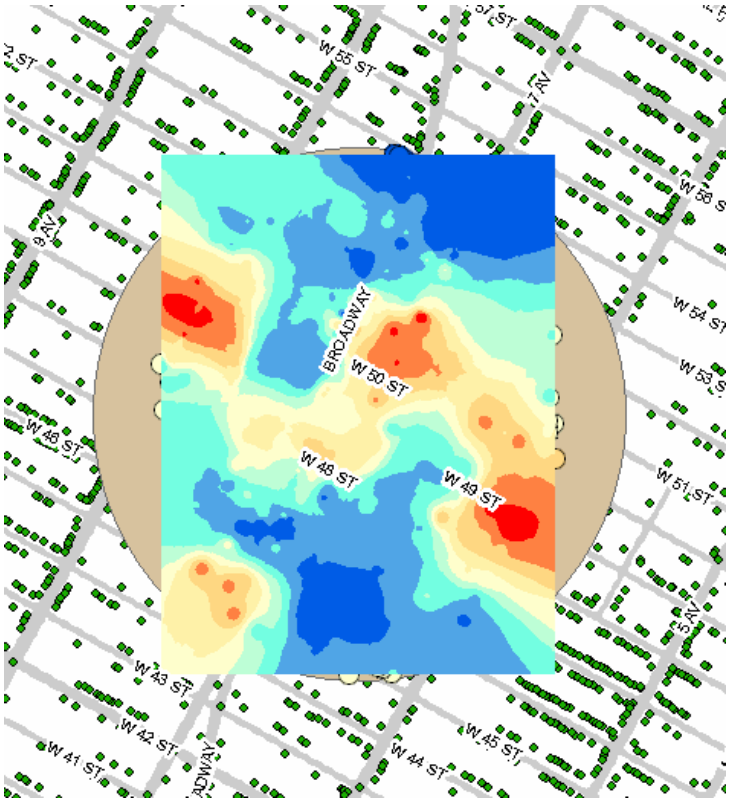

Figure 14: Potential evacuation meeting points within one-quarter mile of the selected business are shown, interpolated into a surface.

Conclusion

It is impossible to separate the spatial component from questions related to retail analysis and business continuity plans. Almost every aspect of retail analysis has a geographic component to it, ranging from where to locate a new store to finding new customers. GIS works hand in hand with other business intelligence tools to provide a complete picture to the analysts and managers tasked with increasing profitability.

BCPs should be flexible enough to enable analysts to analyze and model business work flows, assess potential risks, develop strategies and formal plans, and rehearse and refine those plans. GIS provides the functionality to capture existing and new information regarding assets, employees, transportation routes, and potential targets. By viewing potential risks and company assets on a map, analysts and managers can rapidly access the information they need to make the right decisions in emergency and planning situations.

For more information about the new Spatial Statistics, refer to *The ESRI Guide to GIS Analysis, Volume 2,* by Andy Mitchell.

For more than 35 years ESRI has been helping people manage and analyze geographic information. ESRI offers a framework for implementing GIS technology in any organization with a seamless link from personal GIS on the desktop to enterprisewide GIS client/server and data management systems. ESRI GIS solutions are flexible and can be customized to meet the needs of our users. ESRI is a full-service GIS company, ready to help you begin, grow, and build success with GIS.

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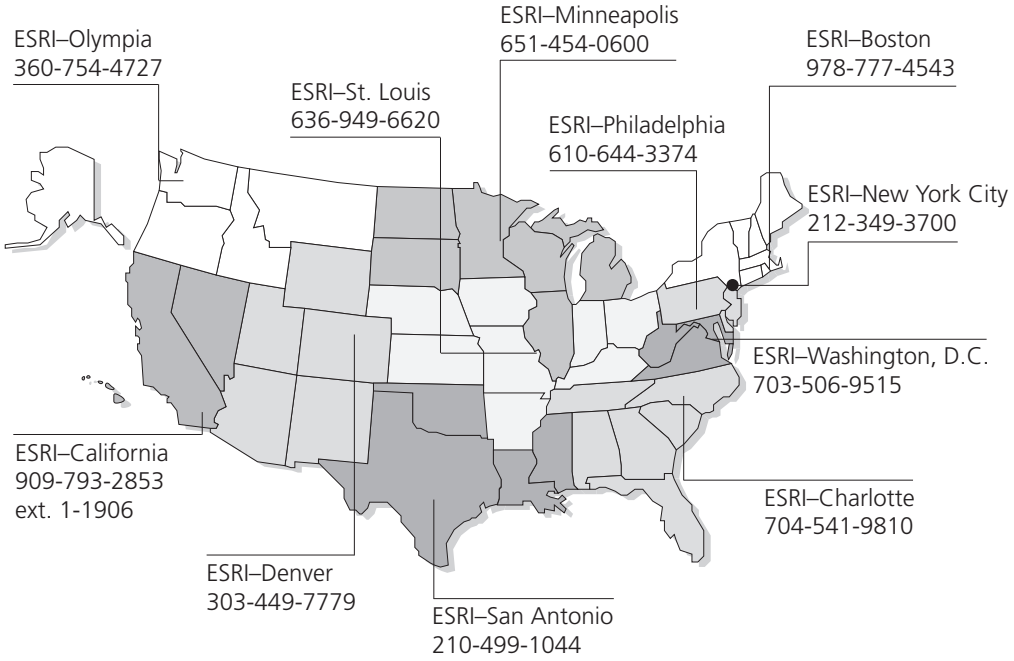

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