Spatiotemporal Hotspots of 2018-2020 Crime in Houston, TX

by

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Abbreviations

COHGIS	City of Houston Geographic Information System
CSV	Comma-separated value
FIPS	Federal Information Processing Standards
GIS	Geographic Information System
HPD	Houston Police Department
LAPD	Los Angeles Police Department
NIBRS	National-Incident Based Reporting System
STAC	Spatial and Temporal Analysis of Crime
NT-STAC	Network Spatial and Temporal Analysis of Crime
NT-SaTScan	Network Spatial and Temporal Scan
ST-DBSCAN	Spatial Temporal Density Based Scan
STKDE	Spatial Temporal Kernel Density Estimation
STSNN	Spatial Temporal Shared Nearest Neighbors
STSSS	Space-Time Scan Statistics
STW	Spatio-temporal Window
WNN	Windowed Nearest Neighbor

Abstract

In 2018, Houston's crime rate was higher than the rates in 95% of U.S. cities. Houston's population is the fourth highest in the nation with more than 2 million people, all of whom are affected by this high crime rate. A better understanding of the spatial and temporal aspects of crime would be useful for law enforcement in protecting the general population. This study analyzed assaults, burglaries, robberies, and thefts in the inner Interstate 610 area of Houston, which is considered downtown. The Houston police department provided crime address data for each crime type from 2018 to 2020. The crime data was geocoded in ArcGIS Pro into point shapefiles and aggregated using counts. The Esri Optimized Hot Spot Analysis and Kernel Density Tools were used to determine crime hot spots for each crime type. The study also explored whether land use type was related to hotspots of certain crimes in the Downtown and Midtown districts of Houston. The study found that the crime hotspots for each crime type occurred mainly in the Downtown, Midtown, and Montrose districts of Houston. Thefts and assaults were higher near the downtown bar district. Theft was also higher near bus stations. The study results could be valuable in helping the police predict and respond to crime hot spots in the future in the Houston area, and the methods used may help the police manage crime in other geographic areas and over different time periods as well.

Chapter 1 Introduction

Crime is a universal problem. Government agencies, and police departments in particular, want to better understand crime rates in their jurisdictions: where it occurs, what occurs, and how these attributes change over time. Geographic Information System (GIS) tools can be used to better understand crime patterns and trends. At the most basic level, by using crime addresses provided by police, these crime occurrences can be mapped spatially. Through using the kernel density and other analysis tools, areas where more and less crime occurs and/or is likely to occur can be identified. From there, one can look at whether or not these locations mirror other features, such as bus stops, entertainment or industrial areas. This information can help police departments trying to reduce crime to better understand past trends and to plan for the future.

This study identifies and analyzes crime hotspots over time in Houston, TX. The study looks at four types of crime: assault, burglary, robbery and theft. A number of maps of different crime types from 2018-2020 illustrate crime trends in the city over time. This study also explored whether certain land uses and point features (e.g., bus stations, bars, etc.) are related with crime types. All of these forms of analysis and visualization help a reader better understand Houston's crime rates and locations. This project helps to better explain crime type locations and changes over time, thus enabling better crime protection in the region. Other police districts may want to replicate this methodology should they have similar goals.

1.1 Project Scale and Study Area

The study area was Houston, TX. More specifically, it was the inner region of Interstate 610, which makes a loop around the central Houston metropolitan area. A small area outside Interstate 610 was also analyzed for crime hotspots because crime still occurs on the other side of the interstate. Houston was chosen as the study site because Houston's crime rate in 2018 was

higher than the rates in 95% of U.S. cities (City-Data.com 2019). Thus, given this high crime rate, this area seemed in particular need of attention. The temporal scale was 2018-2020, which was chosen because it would provide the most recent data for law enforcement officials seeking to use the results of this study to address crime in the city. While this is a very short window, it can at least be suggestive of recent trends.

1.2 Data

A number of data sources were used in this study, which will be discussed in more detail in Chapter 3. Most critical to this analysis was the crime location data. The Houston Police Department (HPD) provided crime incidence data. There are 48 police jurisdictions within the study area, and the crime points were organized and downloaded by police jurisdiction. This included offense type, incident number, street number and name, and time and date for each crime. The types of crime were assault, burglary, robbery, and theft. The crime occurrence data was provided in an excel shapefile with street name and address. This research project could not have been conducted without crime data at this level of precision.

Figure 1 shows a map of the Houston Police Department Police jurisdictions. I-610 is identified to display the boundary between the inner police jurisdictions and the outer police jurisdictions. The small inset map included in Figure 1 references the study area in relation to Harris County. The area in yellow represents no data. This area is monitored by the Bel Air Police Department, not the Houston Police Department. The study area was divided into four district locations: the downtown, midtown, Montrose and Upper Kirby districts. These study districts are shown in Figure 2.

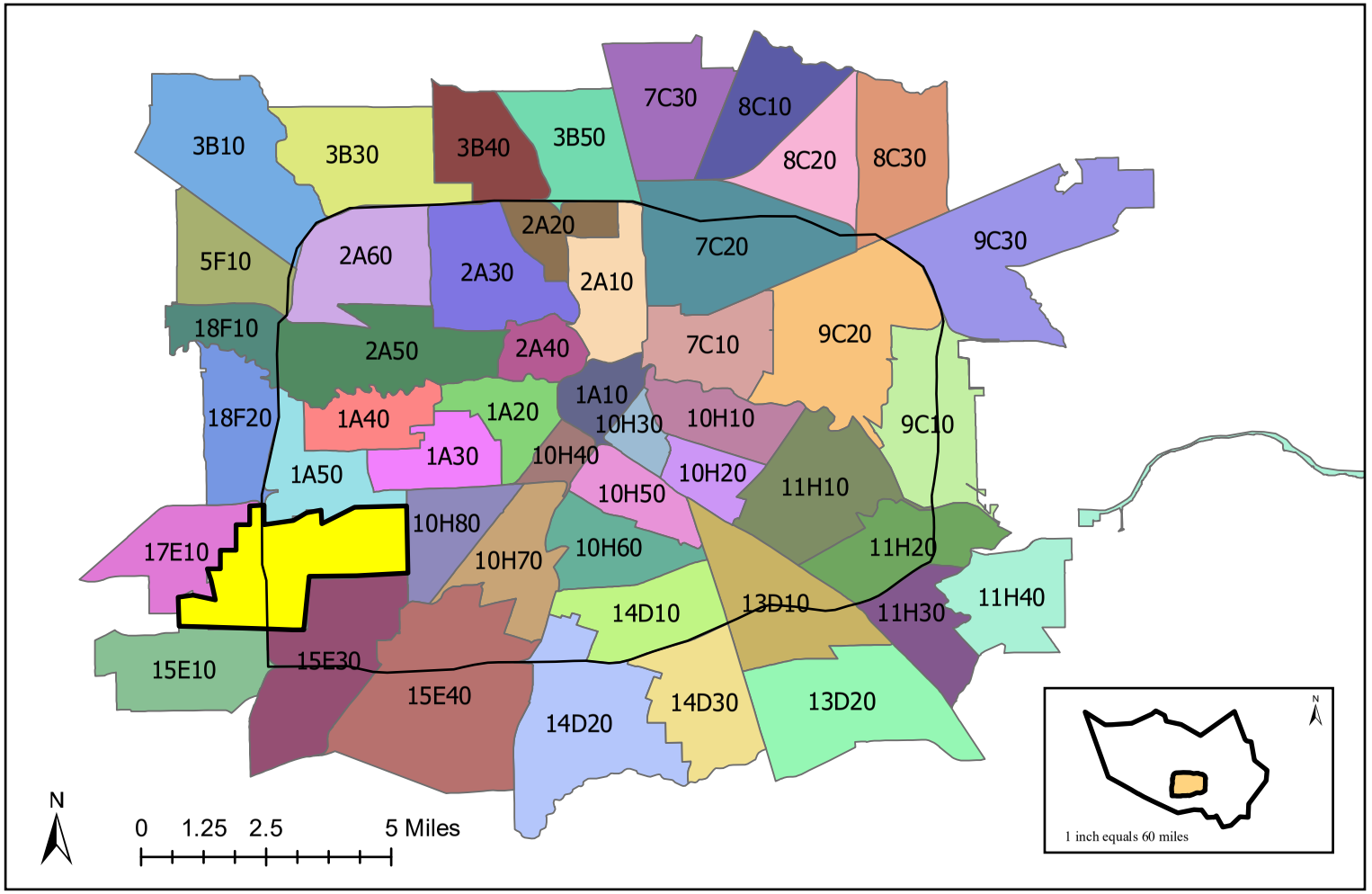


Figure 1. Map of police jurisdictions within the study area. The area in yellow has no crime data and the inset map shows the location of the study area within Harris County, TX.

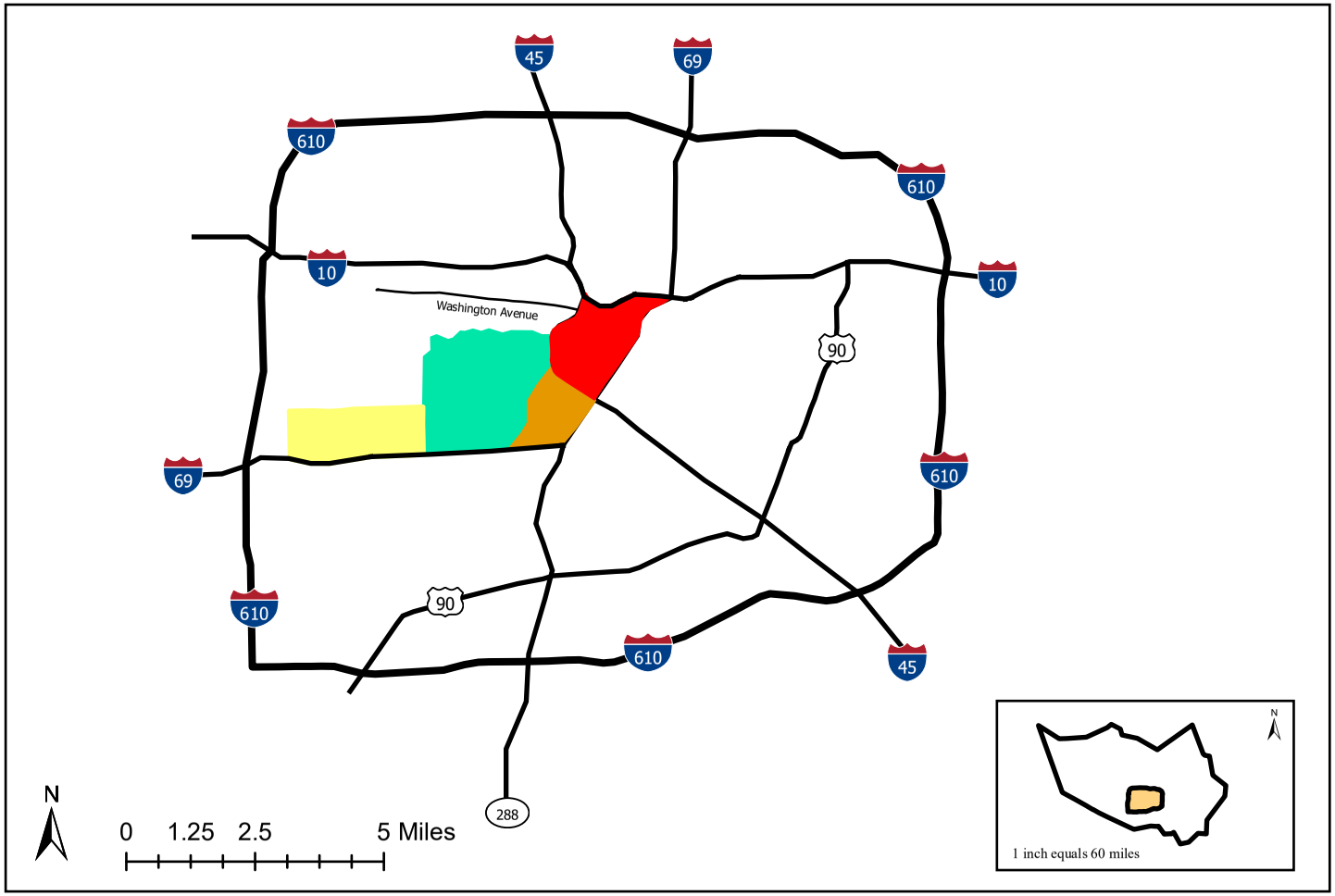


Figure 2. Map showing the major roads and the Downtown (red), Midtown (orange), Montrose (green), and Upper Kirby Districts (yellow) used in this study. The inset map shows the location of the study area within Harris County, TX.

The city of Houston GIS (COHGIS) also provided a land use layer for the study, which included ten land use categories. These data were used to look at the relationship between four specific land use types (single-family, multi-family, commercial, and undeveloped) and high or low crime rates. COHGIS also provided a bus stop layer recording the locations of bus stops within the study area. Past research has shown a relationship between bus stops and crime, and thus this data allowed the relationship to be statistically analyzed.

1.3 Motivation

A spatial understanding of crime hotspots can help prevent loss of life, loss of property and material possessions, and damage to resources generally. The creation of this hotspot analysis for Houston, TX was motivated by the desire to equip law enforcement agencies and organizations looking to deter, suppress, and prevent crime with the tools they need to do so. If the police are aware of the highest crime areas, then they can position crews and patrols in predetermined areas susceptible to higher rates of crime. By showing the specific crime type prevalent in particular areas, which this thesis does, police can better anticipate specific crime types in specific areas. This type of approach can be applied to other metropolitan areas beyond Houston should an analyst have access to similar data.

The second motivation is to inform the general public, especially those residing or visiting the Houston area of crime patterns. If the public is aware of crime hotspots, they may be less likely to enter high crime areas and more likely to take precautions, potentially alleviating pressure on law enforcement. This study could also allow the public to become more vigilant and watchful of suspicious activities in their communities. A reduction in crime can benefit a community by increasing property values, reducing the time and economic cost of crimes that go to trial, and ultimately, increasing the safety of individuals in the area.

1.4 Research Goals

This study had five primary research goals. The first goal was to determine where crime hot spots are located within the city of Houston. The geocoded crime points were used to determine the crime hot spots. The crime hot spots were divided into five classes: very high, high, medium, low, and non-existent. The non-existent hotspots were not included in the study because they were not areas of interest to the target audience, law enforcement.

The second goal of the study was to determine what type of crime occurred in different hot spots. The crime types were analyzed and mapped separately by year. This provided a temporal and spatial visualization of where different types of crime had occurred.

The third goal of the study was to look at how these crime types evolved over time for the period of 2018-2020. The study accomplished this by dividing the crime hotspots into three time periods. The first visualized hotspots that occurred in all three years, the second visualized hotspots that occurred in two of the three years, and the third displayed hotspots that occurred in just one of the three years. For a future study, a fourth section could show areas of the study where no hotspots occurred.

The fourth goal of the study looked at the relationship between local polygons and point features that may be related to different types of crime at different points in time. Point features included bus stops and bars, both of which have been connected with crime in previous studies. Polygons included single-family, multi-family, industrial, commercial, park and open space, and undeveloped land uses. These relationships may point to explanatory features that help law enforcement better understand which areas are particularly prone to crime and thus provide more information to help in their fight to combat crime.

The fifth goal of the study was exploratory, and looked at whether there is a relationship between different types and amounts of crime and natural disasters. Two tropical storms (Beta and Imelda) and one major hurricane (Harvey) occurred before and during this 2018-2020 crime study. The results of this analysis will enable law enforcement to better prepare for changes in crime rates, especially during and following natural disasters when resources may be limited.

1.5 Thesis Structure

The remainder of this thesis consists of four chapters. Chapter 2 describes the related work that informed this study. Past crime research including spatial analysis of crime, analytical techniques, and the relationships between land use and crime are reviewed. Chapter 3 describes the spatial analysis methods and techniques used for this thesis project, including the optimized hotspot tool that was utilized to select land use attributes that fell within the highest crime hotspots with a 99% confidence. Chapter 4 describes and discusses the results of the 2018-2020 hotspot analysis of four crime types in Houston, TX. Heat maps (otherwise known as density maps) were created to show temporal patterns of crime. A number of maps are used to explain the spatial and temporal patterns for each of the four crime types. Chapter 5 offers some reflections as to the strengths and weaknesses of this project, the applicability of this work to similar projects, and suggestions for future research.

Chapter 2 Related Work

This chapter describes the related work for the development of this 2018-2020 Houston, TX crime trend study. Section 2.1 discusses the temporal and spatial extents of related studies and section 2.2 explores whether there is a relationship between place, such as land use, and crime. The final section of this chapter, section 2.3, describes how innovative methods were used in the analysis of crime.

2.1 Temporal and Spatial Extents

Groff and LaVigne (2002) determined that scale and accuracy are important when conducting crime hotspot studies, and that choosing the appropriate temporal and spatial scales for these types of study is critically important. In general, a short time period, such as a month or two, will not provide enough data to delineate accurate crime hotspots (Groff and LaVigne 2002; Spelman 1995). Spelman (1995) suggested that police should use annual crime data instead of weekly or monthly crime data to predict hotspots of crime with 90% accuracy. Groff and LaVigne (2002) described how the geocoding of the crime addresses into coordinates can be used to support spatial analysis and visualization of the crime patterns.

Groff and LaVigne (2002) also discussed choosing the appropriate spatial scale and how the crime data can be aggregated by raster grid cells or police precincts. These authors suggested using square raster grid cells that measured 500 ft on a side to perform crime hotspots in contrast to Gorr and Olligschlaeger (2002), 4,000 ft on a side for optimum hotspot accuracy. The choice of square grid cell size for this study was addressed to determine whether a custom setting should be applied or an Esri default setting should be utilized for the hotspot raster grid cells. A study of violent crime conducted by Esri in 2015 used a distance interval of 1,375 feet to determine violent crime hotspots and an optimal fixed distance band of 4,556 feet. This particular study

suggested examining violent crime hotspots to public high schools (Esri 2015). The abovementioned studies suggested examining different raster grid cell sizes for effective hotspot analysis and using buffers to select certain land use types within a specified distance of the crime hotspots. The use of square grid cells was advocated by Gorr and Olligschlaeger (2002) and Groff and LaVigne (2002).

Groff and LaVigne (2002) also discussed the amount of data that is needed for an accurate study of crime hotspots and suggested that it is important to choose an area that is large enough to provide an adequate number of observations. Gorr and Olligschlaeger (2002) found that a dataset of 30 or more crime occurrences per month provided reliable hotspot accuracy. The study of violent crime conducted by Esri in 2015 had a dataset of over 22,000 occurrences of crime for 2014.

2.2 Place and Crime

The existing literature also documents how certain land use types are related to crime hot spots. Commercial areas, for example, contribute to certain types of crime (Block and Block 1995; Levine, Wachs and Shirazi 1986). Sherman, Gartin and Buerger (1989) showed that half of the crime hot spots in Minneapolis, MN occurred near bars. Roncek and Maier (1991) also discovered a correlation between high levels of crime and bars in Cleveland, OH.

Curry and Spergel (1988) argued that the location where a resident resides is a critical factor in determining whether an individual will participate in criminal activity or not. These authors found crime "to be correlated with poverty and a lack of social control, but violence (e.g., homicide) to be correlated with their measure of social disorganization" (Curry and Spergel 1988, 218). Cohen, Gorr, and Olligschlaeger (1993) found that drug-related crime hot spots occurred near bars, dilapidated commercial buildings, and/or areas associated with poverty.

Levine (2015) found that some types of crime and the associated hotspots occurred in mixed land uses. For example, Canter (2006) demonstrated that more thefts occurred at bus and light rail stations and Paisely (2017) also found that there was a relationship between crime hotspots and distance to metro rails and bus stops.

2.3 The Use of Innovative Methods in Crime Analysis

Nakaya and Yano (2010) employed exploratory data analysis to visualize space time kernel density estimation and scan statistics in Kyoto City during the time period of 2003-2004. The authors used space-time statistical approaches to delineate crime clusters in space and time and space-time cubes to visualize space and time point clustering in a 3D environment. The latter approach displayed where crime hotspots occurred and how long they lasted. Old, persistent, emerging, and new hotspots were delineated utilizing space-time kernel density estimation (STKDE) and space-time scan statistics (STSSS) (Nakaya and Yano 2010). The results of this study showed crime hotspots in the center of the city and around the Kyoto as well as other railway stations. The criminal activities favored areas where criminals had found success in the past, which were labeled as "known crime scenes" (Nakaya and Yano 2010, 237). These authors also suggested documenting crime occurrences on a weekly and/or daily basis.

Another study performed a space-time analysis of crime (STAC) focusing on the downtown area of the Buffalo, NY metropolitan area (Shiode 2011). Numerous authors examined crime hotspot differences at the street level using the Street-level Spatial Scan Statistic and STAC for analyzing street crime occurrences. The aforementioned study used spatial and temporal techniques along with "spatial scan statistics" to detect crime hotspots (Shiode 2011, 365). This method was tested by simulating crime points at the street level which was then compared with street level crime data, focusing on drug-related crimes and robberies in

downtown Buffalo, NY in the mid-1990s (Shiode 2011). The results showed crime trends for both crime types by documenting how the hotspot locations changes over time. Some crime locations remained the same for two years and some new hotspots emerged in 1996. Shiode (2011) determined that the network spatial and temporal analysis of crime (NT-STAC) and network spatial and temporal scan (NT-SaTScan) statistics provided more capable methods for finding hotspots at the street-level. This new method was an adaptation of spatial scan statistics and the classic spatial and temporal analysis of crime and the simulations supported the idea that these two methods are more valuable in finding street crime hotspots than previous methods.

Another study by Li et al. (2018) that focused on earthquakes provided guidance on how to handle hotspots with varying geographic extents. This author explored a new method for finding clusters of occurrences that varied over time and space by identifying occurrences that fall within prominent hotspots. Two parameters were suggested for clustering. The first measured the hotspot mass with respect to space and time, and the second created a mass tolerance for determining important hotspot clusters. Li et al. (2018) used the spatio-temporal density based scan (ST-DBSCAN), windowed nearest neighbor (WNN), and spatio-temporal shared nearest neighbors (STSNN) approaches to find hotspots that had different masses and sizes and concluded that the newer, proposed spatio-temporal window (STW) technique was more successful in finding hotspots with different forms and masses than previous ones. Li et al. (2018, 324) used the term “clusters” to describe earthquake hotspots and this same term was used to define crime hotspots in this study.

Another recent study by Wheeler et al. (2018) introduced two techniques for measuring contrasts in point patterns. The first method analyzed several point patterns and found the discrepancies in the amount of point clustering. When the discrepancies were found, number

breaks could be created from the changes in percentages. This method determined whether or not the discrepancies in the amount of point clustering was important. The second method used regression techniques to determine changes in the size of point patterns over a time period. Wheeler (2018) used these methods to compare the location of where the NYPD pedestrian stops occur and where violent crimes occurred between 2006 and 2016. Two point patterns were statistically analyzed using grid cells to determine the correlation in the number of pedestrian stops and the number of violent crimes. The results showed how the violent crime and police stops remained steady between January 6th and January 13th 2012 and that over the next three days, January 14th- January 16th 2012, the number of police stops dramatically increased and the number of violent crimes trended downward (Wheeler et al. 2018).

The results provided in the Wheeler et al. (2018) demonstrated how knowledge of crime hotspot location could permit the police to reduce the amount of crime in a short period of time by reallocating law enforcement resources. This also means that retrospective studies like this one would benefit tremendously from knowledge of how law enforcement resources were allocated over the period of study. However, these data are seldom available and this makes it difficult to interpret the driving forces for changes in crime patterns.

Chapter 3 Research Design and Methods

Crime data and study location were key factors for this thesis project. The HPD provided crime address data that was geocoded into x,y coordinates. The inner I-610 region of Houston, TX (Figure 1) contained greater than 100,000 crime incidents for the 2018-2020 period. This data was transformed into crime density maps to reveal crime trends and patterns.

The first step of this project was finding the crime data and deciding how to organize it in Excel. The next step was to determine if the crime points had adequate address information. Once crime point address information was confirmed, geocoding was accomplished using the Esri ArcGIS Pro Geocoding Service, CDX Winzip Geocoder in Excel and Geocoding by Smart Monkey in Google sheets. The geocoded crime points were added into ArcGIS Pro using the display x, y coordinates tool to facilitate analysis and visualization.

ArcGIS supports a number of methods for visualization and analysis of crime hot spots and demographics. Within the Esri workspace, the Kernel Density and Optimized Hot Spot Analysis tools were chosen for this study. Once the heat maps were created using the Kernel Density tool, the hotspots were classified into five categories. The Optimized Hotspot tool produced crime hotspots with 99% confidence for this study.

The city of Houston GIS (COHGIS) provided a land use layer with ten different land use types and a bus stop point layer. The land use layer was overlaid on the optimized hotspot areas, and the bus stop point shapefile provided the locations of all of the bus stops within the study area. Both of these datasets were used to explore associations with high crime areas.

The research design is summarized below in Table 1. The workflow used for data acquisition, pre-processing, analysis, and mapping is listed in Table 1 and the six subsections which follow describe the methods and data sources in more detail.

Table 1. Thesis Project Workflow

Fourteen Steps
1. Acquired crime incident dataset from HPD
2. Downloaded data as Excel Spreadsheets
3. Geocoded addresses into latitude and longitude coordinates
4. Organized data spreadsheets by location (police beats), date, and crime type
5. Added crime spreadsheets into ArcGIS Pro as database tables
6. Displayed x, y coordinates as crime points
7. Performed Kernel Density Analysis on crime data
8. Classified the crime hotspots into five categories
9. Performed Optimized Hot Spot Analysis on crime data
10. Mapped crime hotspots
11. Added COH land use layer
12. Added bus stations and bar locations
13. Created multiple maps using a combination of different data layers
14. Exported the maps to 750 dpi PDF format and created final versions of the map

3.1 Description of Crime Attributes

The crime data was downloaded as Excel spreadsheets from the Houston Police Department Crime Statistics for 2018, 2019, and 2020. These data can be downloaded at https://www.houstontx.gov/police/cs/Monthly_Crime_Data_by_Street_and_Police_Beat.htm. The 2019 and 2020 crime data was downloaded for the entire year and the 2018 data were downloaded by month.

The crime points were provided as rows in Excel spreadsheets with associated addresses (street numbers and names), type of crime, and crime date. There were 100,791 total crime occurrences in this dataset. The Excel spreadsheets were converted into CSV (comma-separated value format), tables and were then added into ArcGIS Pro as database tables.

The attributes accompanying each of the crime points included incident number, occurrence date, occurrence hour, crime offense type, beat, premise, block range, street name, type of street, city, state, and ZIP code. The HPD switched to the National-Incident Based Reporting System (NIBRS) in June 2018 and prior to June 2018, the HPD used the Uniform Crime Reporting

system. The pre-June 2018 attributes were date, hour, crime offense type, beat, premise, block range, street name, and type of street. The CDX WinZip tool in Excel was used to find ZIP codes for each of the pre-June 2018 crime data points using block number, street name, city, and state. The CDX Locate Bing Function was used to find pre-June 2018 ZIP codes. Three columns in Excel were created for the pre-June 2018 spreadsheets that included city, state, and CDX WinZip located ZIP code.

3.2 Organization of Crime Data

The HPD crime data was organized by police beats, also known as police jurisdictions. The police beat data was obtained from the HPD Crime Statistics (City of Houston Police Department 2021 a and b). A filter was run on the police beat column to select the 48 police jurisdictions located within the study area. A second filter was used to select the four crime types for this study and another filter was used to separate the yearly data into monthly data.

The four crime types varied depending on the database used. The pre-June 2018 crime types were Assault (aggravated assault), Burglary (burglary), Robbery (robbery), and Theft, (auto theft and theft). The post-June 2018 crime types were Assault (aggravated assault, simple assault), Burglary (burglary, breaking and entering, burglary), Robbery (pocket-picking, purse-snatching, robbery), and Theft (stolen property offenses, theft from buildings, theft from motor vehicles, and theft of motor vehicle parts or accessories). These later crimes were collapsed to match the pre-June 2018 crime types, as discussed in the next paragraph.

Crime types were aggregated for analysis. For example, all theft categories were combined into a single category whether there were two attribute categories (pre-June 2018) or four attribute categories (post-June 2018). Aggravated assault and simple assault were aggregated. This study matched the post-June 2018 crime types with the pre-June 2018 crime

types. The 2019 and 2020 crime data were merged into one Excel spreadsheet for each year. The pre-June 2018 data was organized by month with the data for the remainder of 2018 combined into one annual spreadsheet. SQL was used to filter crime types in ArcGIS Pro.

3.3 Geocoding of Crime Addresses

The crime point data was downloaded from the HPD for all three years, 2018-2020. The 2020 crime data was geocoded using Esri's World Geocoding Service. The 2018 and 2019 crime data was geocoded using the CDX WinZip geocoder tool in Excel. These tools turned street addresses into latitude and longitude coordinates. Geocoding by Smart Monkey in Google sheets was utilized to geocode the 2% of crime addresses that could not be located with Esri World Geocoding Service and/or CDX WinZip.

3.3.1 Geocoding in Excel using CDX WinZip

The CDX WinZip geocoder was downloaded for Excel as an add on. The address provided by the HPD for the 2018 and 2019 crime data was divided into five columns: street number, street name, city, state, and zip code, and a formula was created in Excel to merge these five columns into one that showed the full address.

The Insert CDX LocateBing Function was opened and a single line address was entered for a selected row and column. The copy function was used for the entire column, which allowed 3,000-5,000 monthly crime events to be geocoded at a time using the executive formula button. This first run produced geocoded addresses with a high level of confidence using Bing Maps. The Bing maps tool specifies accuracy as High, Medium or Low confidence and the 2% of the addresses that could not found with high confidence were not returned with latitude and longitude coordinates. A column was then created to display the geocoding confidence level for each crime address. This confidence level provided an accuracy assessment of the geocoded

location of the given latitude and longitude coordinates. The next paragraph describes the methods used to handle the second run of crime occurrence addresses.

The addresses that were not found on the first run were rerun, this time with the Allow Ambiguous Data box checked. This function allowed addresses to be geocoded with medium confidence. With this second run, almost all (i.e. 95-98%) of the crime addresses for 2018 and 2019 were located using Bing Maps. This also generated latitude and longitude in the same column, which was problematic for future analysis. Latitude and longitude needed to be in two separate columns in Excel for use with the ArcGIS Pro XY Table to Point tool. The Excel text to columns tool was used to separate the combined latitude and longitude columns. The 2-5% of the crime addresses that were not located with the CDX Winzip geocoder used another geocoder in Google Sheets. The Geocoding by Smart Monkey tool is discussed in the next section.

3.3.2 Geocoding in Google Sheets using Geocoding by Smart Monkey

For the addresses that were not found during the first and second geocoding attempts in CDX WinZip, the Geocoding by Smart Monkey application was downloaded in Google Sheets. Geocoding by Smart Monkey was used to try and find the 2% of the CDX WinZip location points not found. A template was created for street number, street name, city, state, and ZIP code. The unlocated geocoding addresses were added into the Geocoding by Smart Monkey template and this approach was able to find almost all of the addresses that were not successfully geocoded on the first and second runs of the CDX WinZip tool.

The two CDX WinZip runs and Geocoding by Smart Monkey were utilized for all the 2018 and 2019 crime points and the results were merged to produce a master spreadsheet for each year. The 2020 crime points were all geocoded using Esri's World Geocoding Service. The next section briefly describes this geocoding method using the Esri application in ArcGIS Pro.

3.3.3 Geocoding in ArcGIS Pro

The 2020 crime was geocoded using the ArcGIS World Geocoding Service. This is the third geocoding service used in this study. Three different geocoding tools were used in this study as a test of geocoding effectiveness. The ArcGIS World Geocoding Service was the most time-efficient of all the geocoding methods used for this thesis project. The addresses were imported as a single-line address format and the Esri World Geocoding Service was used to convert addresses into x and y coordinates.

This study also used the Esri World Geocoding Service to geocode the crime addresses for July-December 2020 that fell on the outer boundaries of I-610. These crime addresses were downloaded from the HPD and were utilized to evaluate crime edge effects. This added an additional 13,944 crime occurrences to the study data set and another 17 police precincts to the study area. The Esri World Geocoding Service was used to geocode all of these crime addresses, with 2.8% of the crime points being identified as in the same location.

3.4. Spatial Analysis of the Crime Data

The 2018 and 2019 master spreadsheets were imported into ArcGIS Pro as standalone tables. The display x, y data tool was selected by using the XY Table to Point geoprocessing tool. The coordinate system was GCS_WGS_1984 W. This projection was chosen because it matched the COHGIS street layer and the COHGIS land use layer.

The Kernel Density and Optimized Hot Spot Analysis methods were selected to analyze the crime data in Houston, TX. The Kernel Density tool was used to determine crime hotspots for the period 2018-2020. The crime points were aggregated by using counts within raster grid cells using the fishnet grid method for both the kernel density and the optimized hot spot analysis methods.

The Kernel Density method produced interval value densities of crime counts. The interval values offer a range of numbers and specify the confidence of a hotspot. Taking the 2019 Robbery dataset with 2,810 crime points as an example, the interval value range was $\leq$ 728,436 and $\geq$ 145,687. These interval values were classified into five hotspot categories: Very High, High, Medium, Low and Very Low crime densities. For the 2019 Robbery dataset, these densities were represented by 728,436, 582,749, 437,062, 291,374, and 145,687, respectively. The study focused on the very high, high and medium hotspots, but some low hotspots are mentioned in the results section. The very low hotspot categories were not considered further in the study because they were seen as the least necessary with respect to the priorities of police, the target audience for this study.

Esri's default settings were used with the Kernel Density and Optimized Hotspot Analysis tools to execute and delineate crime hotspots. The settings used by Esri (2015) did not work for all the kernel density and optimized hot spot maps in this Houston crime study. The Esri (2015) used a small number of crime occurrences compared to this Houston crime study.

This Houston crime study volume used tens of thousands of occurrences of crime for each year and crime type. Therefore, the Esri default settings were able to determine hotspot densities even when there were a large volume of crime occurrences concentrated in close proximity to each other. The trials using the customized settings generated an error message. This study also used Esri default settings to determine raster grid sizes because these settings accounted for the largest numbers of crime occurrences.

The Optimized Hot Spot Analysis method implemented in ArcGIS Pro determined the locations and accompanying probabilities of crime hotspots, with Gi Bin Level 3 statistics suggesting a 99% chance of a hotspot. Parameters were set by using the Esri default setting's

grid cell size and distance bands. The use of Esri's customized settings created crime density maps from the HPD geocoded crime points.

Using crime occurrence incidences, the optimized hot spot analysis tool produced a map with high statistical confidence of hot and cold spots using ArcGIS Pro's Getis-Ord Gi statistics. The Gi_Bin statistics made up of z-scores and p values show the significance of hot and cold spots. The z-scores represent standard deviations and the p values show the probability and confidence levels. The Gi Bin z-scores are either +3 or -3 and reflect the 99% confidence level, whereas the +2 or -2 bins reflect the 95% confidence level, and the +1 or -1 bins reflect the 90% confidence level (Esri 2021). The negative (-) and positive (+) signs represent cold and hot spots, respectively. This study used the Gi Bin level (+) 3 to delineate crime occurrence hotspots at the 99% confidence level.

3.5 Land Use and Optimized Hotspots

The COH land use layer, downloaded from the City of Houston, was clipped so that only attributes within the study area were visible and projected in WGS 84. There were 205,711 individual land use attributes that fell within the study area representing 10 land-use categories. They are Agriculture Production, Commercial, Industrial, Multi-Family, Office, Park and Open Space, Public and Institutional, Single-Family, Transportation and Utility, and Undeveloped Land Use. The acreages for each land use type were recorded in this dataset.

The land use types that fell within these Gi Bin Level 3 crime hotspots were selected for further analysis. The select by location query tool was used to select these land use attributes within the polygon (boundary) of the Gi Bin Level 3 crime hotspots. The land use statistics provided percentages of what type of land use was most prevalent in each optimized crime hotspot location for each type of crime.

The optimized hotspot tool was conducted on all four crime types for 2020 and given the land uses included in the areas with hotspots, the study focused on Commercial, Industrial, Multi-Family, Single-Family, Park and Open Space, and Undeveloped land uses. Kernel density analysis was conducted on the bus stop point layer, downloaded from the City of Houston, to determine the density hotspots of bus locations. The results of this bus stop kernel density analysis is displayed in Appendix C. Appendix A shows bus stop density and the location of 2020 Theft hotspots. The final part of the analysis examined the associations between commercial land uses, such as bars, and bus stop locations with the crime hotspots. The bar locations within the study districts are shown in Appendix B. The results of these findings will be discussed in the next chapter.

Chapter 4 Results

Table 2 lists the 2018-2020 crime statistics and shows that thefts and assaults exceeded burglaries and robberies in all three years by considerable margins. The overall totals point to more than 40,000 crimes with higher numbers in 2019 compared to the two years that proceeded this particular year.

Table 2. 2018-2020 Crime Statistics

Year	Assault	Burglary	Robbery	Theft
2018	8,032	4,417	2,224	12,597
2019	12,385	5,239	2,810	15,954
2020	12,013	4,463	2,366	11,926
Totals:	32,430	14,119	7,400	40,477

The first section below looks at the location of the crime type locations within the study area. The hotspots were categorized using 5 classes. The classes are very high (5), high (4), medium (3), low (2), and very low (1). The study focused on the very high and high hotspot crime types. The medium hotspot areas are also important because these areas could become problematic in the future.

4.1 Crime Trends and Results of all Crime Type hotspots

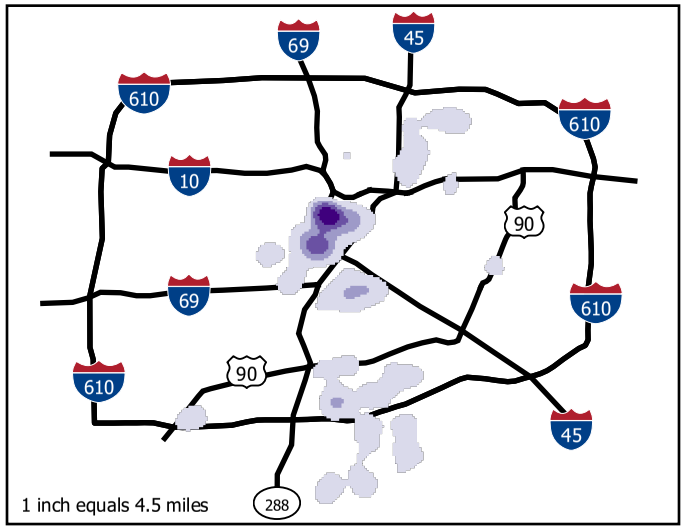
4.1.1 2018-2020 Assault Hotspots

The 2018 category 5 and category 4 assault hotspots occurred mainly in the midtown-10H40 and downtown 1A10 districts (Figure 3a). A large category 5 and category 4 hotspot of 2018 Assault occurred in the western to northwestern portion of the downtown district. This was further north than the 2019 and 2020 category 5 and category 4 assaults (Figures 3b and 3c). This category 4 and category 5 hotspot extends south by a narrow category 4 hotspot to another category 5 and category 4 hotspot cluster. This category 5 and category 4 hotspot is located in

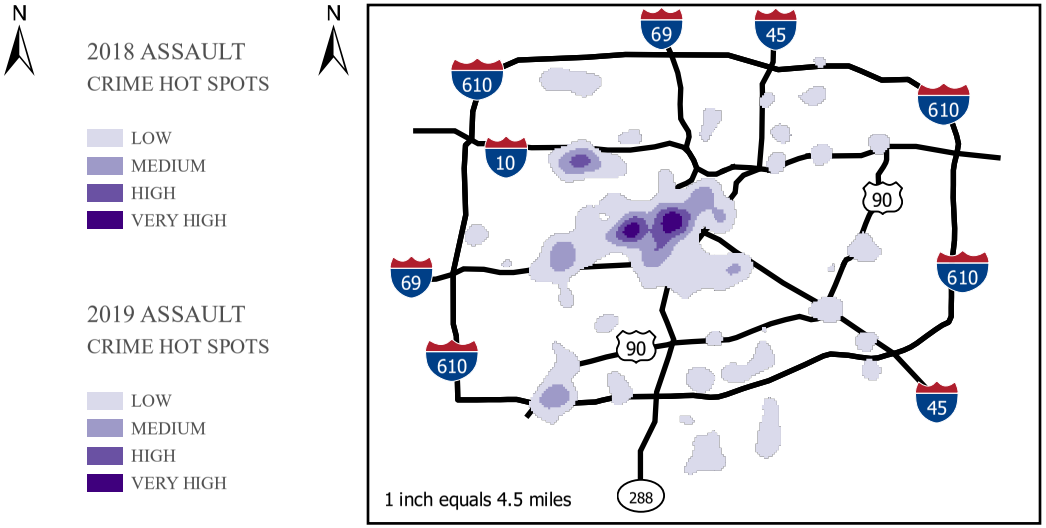
the northern portion of the midtown district near I-45 (Figure 3a). This category 5 and category 4 hotspot in 2018 is near the same location as the 2020 category 5 and category 4 cluster and just east of the two 2019 category 5 and category 4 2019 assault hotspot clusters (Figures 3b and 3c).

In 2018, the remaining and majority of the remainder of the downtown district experienced category 3 and category 2 hotspots. The category 2 hotspots in 2018 was smaller than in 2019 and 2020. The category 2 cluster was located in the downtown and midtown districts in 2018. In 2018, the Montrose district has a small cluster of category 2 in the central portion of the district. In 2019, the category 2 extended across the Montrose district and into the Kirby District. In 2020, this category 2 diminished to the intersection of Westheimer and Lincoln where a small category 3 occurred.

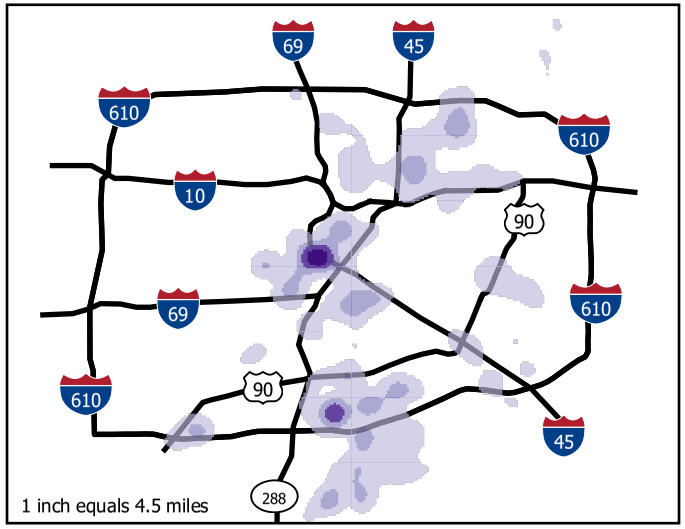
In 2019, a larger category 5 and category 4 hotspot occurred at the intersection of the Montrose district 1A20, Midtown 10H40, and Downtown 1A10 districts on I-45 near the same location in 2020 (Figure 3b). This large problematic assault hotspot concentration is centered at the northwest portion of the midtown district. In 2019, another category 5 and category 4 cluster emerged in the central Montrose district that was not present in 2018 and 2020. This category 5 and category 4 in the downtown and midtown districts were connected by a narrow category 4 hotspot in 1A20 Montrose in 2019 (Figure 3b). The category 3 in 2019 covered most of the Montrose, midtown, and downtown districts and was much larger than in 2020 (Figure 3c). The category 3 was confined to the downtown and midtown districts in 2018 and 2020. This category 3 cluster extended into the center of the Montrose district in 2019. The three parts of Figure 3 show how assault dramatically expanded from 2018 to 2019 in the downtown and midtown districts and then diminished in area in 2020. The location of the downtown, midtown and Montrose districts are displayed in Figure 2. The police jurisdictions are shown in Figure 1.



(a) Assault Hotspots in 2018



(b) Assault Hotspots in 2019



(c) Assault Hotspots in 2020

Figure 3. 2018-2020 Assault Crime Hotspots

In 2019, the majority of the downtown, midtown and Montrose districts experienced a large category 2 cluster. This category 2 cluster fully covered police jurisdictions 10H60, 10H50, 10H30, 1A10, 1A20, 10H40, 10H70, and 1A30 in 2019. A very large category 2 expanded from the Kirby District to the Montrose District and covered the majority of the midtown and downtown districts in 2019. In 2018, this category 2 was just a cluster at Westheimer and Lincoln (Figure 3a.). In 2020, the category did not extend past Westheimer and Lincoln in the Montrose district (Figure 3c).

In 2019, another category 5 and category 4 cluster emerged in the central Montrose district that was not present in 2020 at the intersection of Westheimer and Lincoln. This category 5 and category 4 cluster connects to the large category 5 and category 4 in the downtown and midtown districts by a narrow category 4 hotspot in 1A20- Montrose. The category 3 cluster in 2019 covered most of the Montrose, midtown, and downtown districts and was much larger than in 2020. The category 3 cluster extended into the center of the Montrose district.

Category 5 and 4 assault hotspots also occurred near the intersection of the midtown 10H40 and downtown 1A10 districts on I-45. This category 4 and 5 hotspot is surrounded by a category 3 hotspot in 10H40, 1A10 and 1A20 Montrose. The remaining areas of the downtown and midtown saw category 2 assault hotspots. The Montrose District has a small category 3 cluster surrounded by a large area of category 2 hotspots. The category 3 cluster in the downtown and midtown district extends 2.48 miles from the southwest to the northeast. From the northwest to the southeast, the longest point is 1.2 miles across.

The other category 3 clusters in 2020 occurred at Sampson and Elgin, at the intersection of Cavalcade and Lockwood and Liberty and I-69. These category 3 clusters are surrounded by a large category 2 cluster. In 2019, the category 3 clusters disappear and six small category 2

clusters pop up in the northeast section of the study. A category 3 cluster occurred at Kirby and I-69 in 1A30 in 2019. In 2020, there were no hotspots of assault in any category at Kirby and the I-69.

In 2018 and 2020, there were no category hotspots that occurred along Washington Avenue. In 2019, a new category 4 and category 3 cluster emerged on Washington Avenue centered at Durham and Allen in 2A50. A large category 2 assault cluster surrounded this category 4 and category 3 cluster along Washington Avenue in 2019. In 2020, there were no assault hotspots along Washington Avenue.

In 2018, a small category 3 cluster existed at Scott and Amos in the southern section. In 2019, this small category 3 diminished to a category 2 cluster. Then in 2020, this cluster remerged as a medium sized category 4 surrounded by a category 3 cluster. 2018 also saw a large category 2 cluster from Scott to the west and MLK to the northeast of I-610. Medium sized category 2 clusters occurred at Sunbeam and Scott and Wilmington and Cullen. The category 2 cluster ran north to south along Cullen south to Sunbeam in 2018. Another large category 2 cluster occurred at Bellfort and MLK. In 2018, there were only category 2 clusters in the southern section except for a small category 3 cluster at Scott and Amos.

In 2020 in the southern portion of the study east of the intersection of 288 and I-610, a small category 4 hotspot occurred in 14D20 and 14D10 in 2020, at the intersection of Scott and Corder. It is surrounded by a cluster of category 3 hotspot.

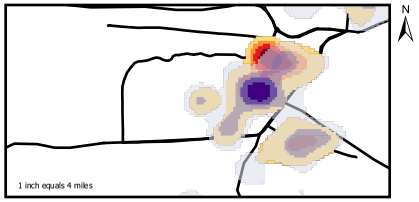
There are five other category 3 clusters in the southern section in 2020. One occurs near Yellowstone and Cullen, and the others occur near Milart and MLK, Cullen and I-610, Sunbeam and Scott and Sunbeam and Cullen. A large category 2 cluster completely covers police beats 14D20, 14D30, 14D10 and 10H60. The category 2 cluster located east of 288 and north of I-610 ran east to west 2.86 miles and 1.95 miles north to south. South of I-610 and east of 288, this

category 2 ran 3.72 miles from the southwest to the northeast and 2.43 miles from north to south in 2020.

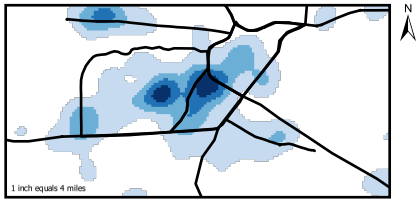
In 2019, the category 4 and category 3 cluster at Scott and Corder diminished to a small category 2 hotspot. The other two category 2 s north of I-610 also diminished to a medium sized category 2. The large category 2 in 2020 covering all of 14D20, 14D30, 14D10 and 10H60 dissipated into small category 2 clusters at Sunbeam and Scott and Sunbeam and Cullen. In both 2019 and 2020, a medium sized category 3 and 2 cluster occurred at 90 and I-610. All three years saw a category 2 cluster at Canal and Wayside.

At Fulton and Morris, a category 2 cluster existed in both 2019 and 2020. At I-10 and 69 in 2018, a category 2 hotspot occurs north of I-10. The category 2 is east of 69 and spreads up and along 69 from the north to the south in 7C10 and 7C20. This large category 2 southern border is I-10, 69 to the east and Crane to the north. East of I-69, the western portion runs 1.89 miles north to south down Gregg and 0.82 miles from west to east along Crane in 7C20 in 2018. This large category 2 hotspot along Crane occurs from I-69 to the west and Hoffman to the east in 7C20 in 2018.

Figure 4 shows the assault hotspots that occurred in just one year, in two of the three years and hotspots that occurred in all three years. Figures 4(a) and 4(b) show how assault in 2019 was much more expansive in the downtown and midtown districts than in 2018 and 2020. Figures (4 c-f) show the 2019 assault hotspots that only occurred in specific areas of the study in that one year. Figures (4 g-i) show the northern, southern and southwestern areas of the study where hotspots occurred in all three years. Figures (4 j-m) display the southern and southeastern areas of the study area where hotspots occurred in two of the three years.

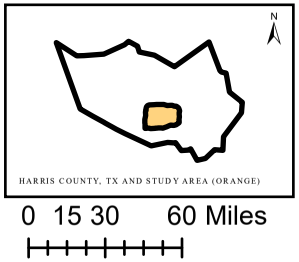


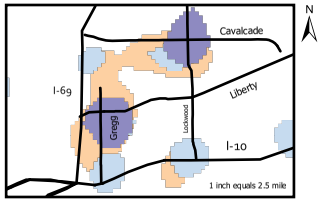
(a) Overlay of 2018 and 2020 Assault Hotspots



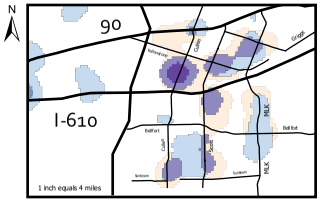
(b) 2019 Assault Hotspots

(a) and (b) 2018-2020 Assault Hotspots in all 3 years

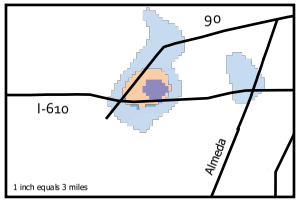




(g) 2018-2020 category 3 and category 2 hotspots between Cavalcade and I-10.

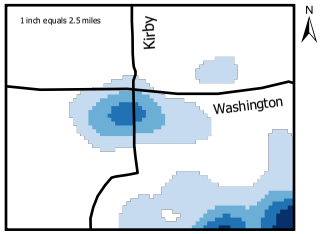


(h) 2018-2020 category 4, 3 and 2 hotspots in the southern section.

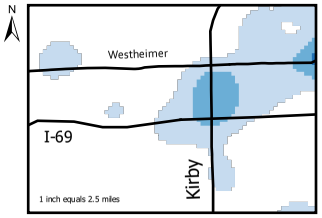


(i) 2018-2020 category 3 and category 2 hotspot cluster at the intersection of 90 and I-610.

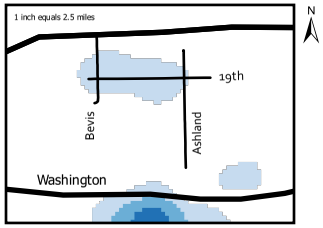
(g) - (i) Assault Hotspots in all 3 years



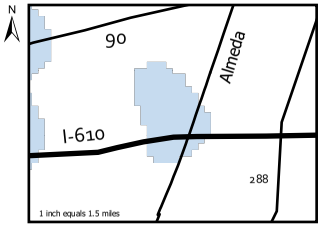
(c) 2019 category 4, category 3 and category 2 hotspot cluster along Washington Avenue.



(d) Category 3 and category 2 hotspot cluster at Kirby and I-69. There is another small category 2 cluster on Westheimer near I-610.

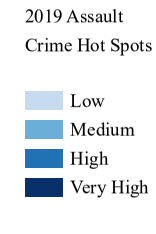


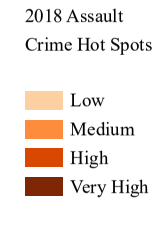
(e) 2019 category 2 cluster along 19th between Bevis and Ashland in the NW section.

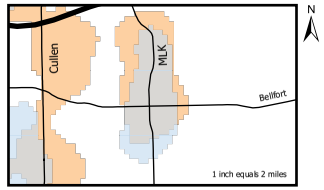


(f) 2019 category 2 at I-610 and Almeda.

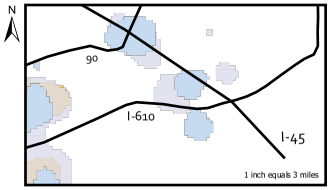
(c) - (f) 2019 Assault Hotspots



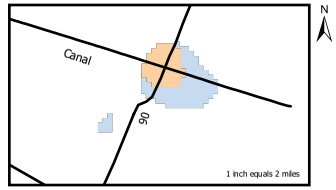




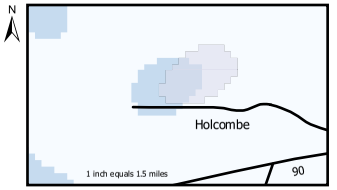
(j) 2018-2020 category 2 hotspots south of I-610.



(k) SE section hotspots for 2019 and 2020.



(l) 2018 and 2019 category 2 assault hotspot at Canal and 90.



(m) 2019 and 2020 category 2 along Holcombe.

(j) - (m) 2018-2020 Assault Hotspots in 2 years

Figure 4. Frequency of Assault Hotspots

In the northeast portion of the study area north of I-10 and east of 69 in 2019, there are small category 2 clusters. Three of these category 2 clusters are on I-10. The western category 2 is 0.45 by 0.58 miles in 7C10 at Gregg and I-10. The second one is 0.5 by 0.59 miles in 7C10 at Lockwood and I-10. The eastern one is 0.5 by 0.56 miles in 9C20 at Harbor and I-10. A small category 2 cluster occurs at Gregg and Liberty. At Lockwood and Cavalcade, a medium sized category 2 exists. A very small category 2 cluster occurs at I-69 and Collingsworth. At Lockwood and I-610, a very small category 2 cluster exists.

In the northwest portion of the study area, from west to east there is a category 2 hotspot that extends from Bevis to Ashland in 2A60 and 2A30 in 2019. This category 2 cluster runs 1.45 miles east to west and 0.68 miles north to south. A large category 2 cluster occurs at MLK and Bellfort with another large category 2 cluster between Scott and Cullen south of Bellfort in 2019.

A large area of category 2 (low) hotspots occurs northeast of the intersection of Interstate 10 and I-69 in 2020. One cluster of category 3 (medium) hotspots occurs along and just east of I-69 and north of I-10. This category 3 cluster runs 0.66 by 0.76 miles. Another category 3 cluster occurs at the intersection of Cavalcade and Lockwood and runs 0.62 by 0.9 miles.

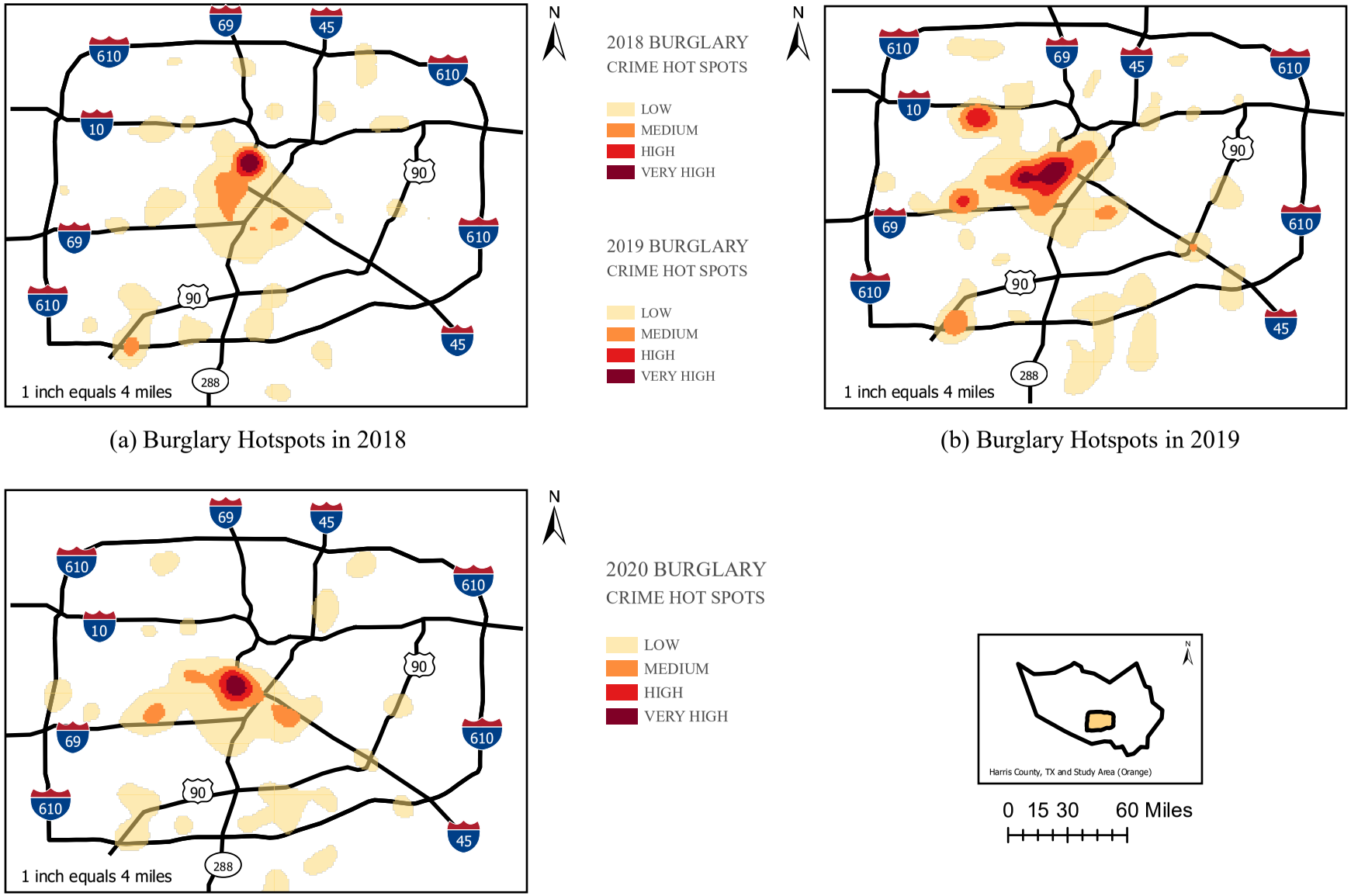
A category 2 hotspot assault runs along I-10 from the intersection I-69 and I-10 to the east for over 3 miles in 2020. This category 2 is 4.32 miles at the longest point from west to east and 3.4 miles at the longest point from north to south. The western portion of this large category 2 hotspot is between I-45 to the west and I-69 to the east. The center of this category 2 is near Fulton and Morris in 2020. In 2018, there are two medium sized category 2 clusters at Gregg and Liberty and along Crane.

4.1.2 2018-2020 Summary of Burglary Hotspots

The 2018 burglaries occurred mainly in the midtown and downtown districts (Figure 6). Just east of the intersection of Allen and 45 in the downtown district, there was a large category 5 and 4 cluster of burglary in the downtown district. This category 5 and category 4 hotspot was north of the 2019 and 2020 category 5 and category 4 hotspots along the western border of downtown. The category 3 extends from the southwest portion of the midtown district along the western borders of the midtown and downtown districts all the way to the northwest portion of the downtown district. The remaining portions of the midtown district saw a category 2 hotspot. The eastern, southeastern, and central portions of the downtown district experienced a category 2 hotspot. The central to eastern half of the Montrose district is a category 2 hotspot. The eastern Montrose border area saw a category 3 hotspot in 2018. The majority of the Kirby district experiences a category 2 hotspot in 2019.

A larger category 5 and 4 burglary hotspot occurred near the intersection of the Montrose 1A20, Downtown 1A10 and Midtown 10H40 districts in 2019. This category 5 hotspot was located in the northwest portion of Midtown and the eastern portion of the Montrose district, near the intersection of Brazos and I-45. The central and eastern portion of the Montrose District in 2019 saw a large category 5 and category 4 hotspot that was part of the same large category 5 and category 4 hotspot in the northwestern midtown district. The majority and/or entire Montrose, Downtown and Midtown districts was covered in category 3 and category 2 hotspots for 2019. This category 5 and 4 hotspot grew and expanded into Montrose from 2020 to 2019. The large category 2 hotspot was present in both 2020 and 2019 and both were much larger in 2019.

Several category 5 and 4 burglary hotspots occurred near the intersection of the downtown 1A10 and midtown 1040 districts near Louisiana and I-45 in 2020. One category 5



(a) Burglary Hotspots in 2018

(b) Burglary Hotspots in 2019

(c) Burglary Hotspots in 2020

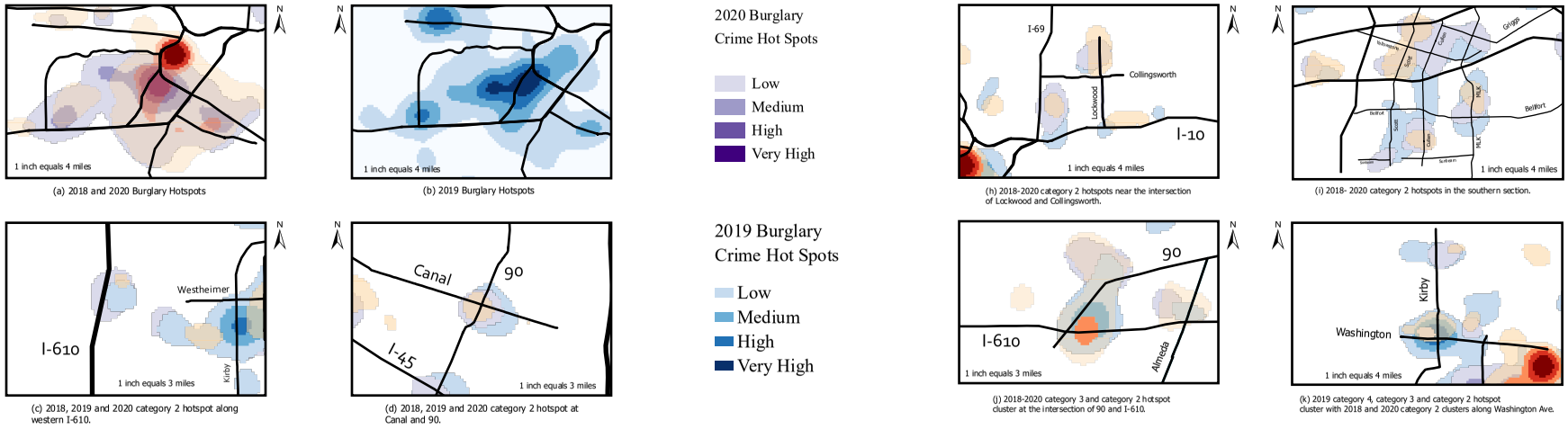
Figure 5. 2018-2020 Burglary Crime Hotspots

and category 4 hotspot occurred near the same location as the category 5 and category 4 cluster in 2019. A substantial category 3 hotspot surrounded this category 4 and 5 hotspot and covered portions of the downtown, midtown, and Montrose districts. This category 4 and 5 hotspot was located in the northwest portion of the midtown district. A very large category 2 hotspot covered the remaining southwest portions of midtown, southern downtown, the majority of Montrose and the Kirby district.

There was a small category 3 cluster at Shepherd and I-69 in 1A30 in 2020. A small cluster of category 4 and 3 occurred near Kirby and I-69 in 1-30 in 2019. In 2018, there was just one small category 2 cluster at Kirby and I-69. A large category 4 and 3 hotspot occurred along Washington avenue at Durham in 2A50 in 2019. An expansive category 2 hotspot occurred along Washington avenue from Westcott to the west and Studemont to the east in 2019. This category 2 hotspot in 2019 was so large that it connected to the Montrose District category 5 and category 4 hotspots to the south on Studemont Street.

In 2020, Washington Ave saw only two small category 2 clusters. In 2018, Washington Ave had just one medium sized and one small category 2 cluster. Burglaries were much more prevalent on Washington Ave in 2019. There was a category 2 cluster between TC Jester and Thompson along Washington Avenue in 2018. At Washington Avenue and the I-45, a category 2 hotspot extends out to the north from the large category 5 and category 4 hotspot at Allen and I-45 in 2018.

Figure 5 summarizes the 2018-2020 burglary crime trends. All three years showed a large category 5 and category 4 hotspot cluster on I-45 near the intersection of the downtown and midtown districts. From 2018 to 2019, this large category 4 and category 4 cluster expanded into the eastern Montrose District and then diminished to a smaller size in 2020. Figure 6 summarizes the frequency of burglary crime trends.



(a) - (d) 2018-2020 Burglary Hotspots in all 3 years

(h) - (k) 2018-2020 Burglary Hotspots in all 3 years

(e) - (g) 2018-2020 Burglary Hotspots in just 1 year

(l) - (n) Burglary hotspots in 2 years

Figure 6. Frequency of Burglary Crime Hotspots

A large category 2 cluster occurred south of 288 and I-45 and northeast of 288 and I-69 in all years. To the southwest of 288 and 45, there was a category 3 cluster at Sampson and Elgin in 10H50 in all three years. From 2019 to 2020, this category 3 hotspot gradually increased in size.

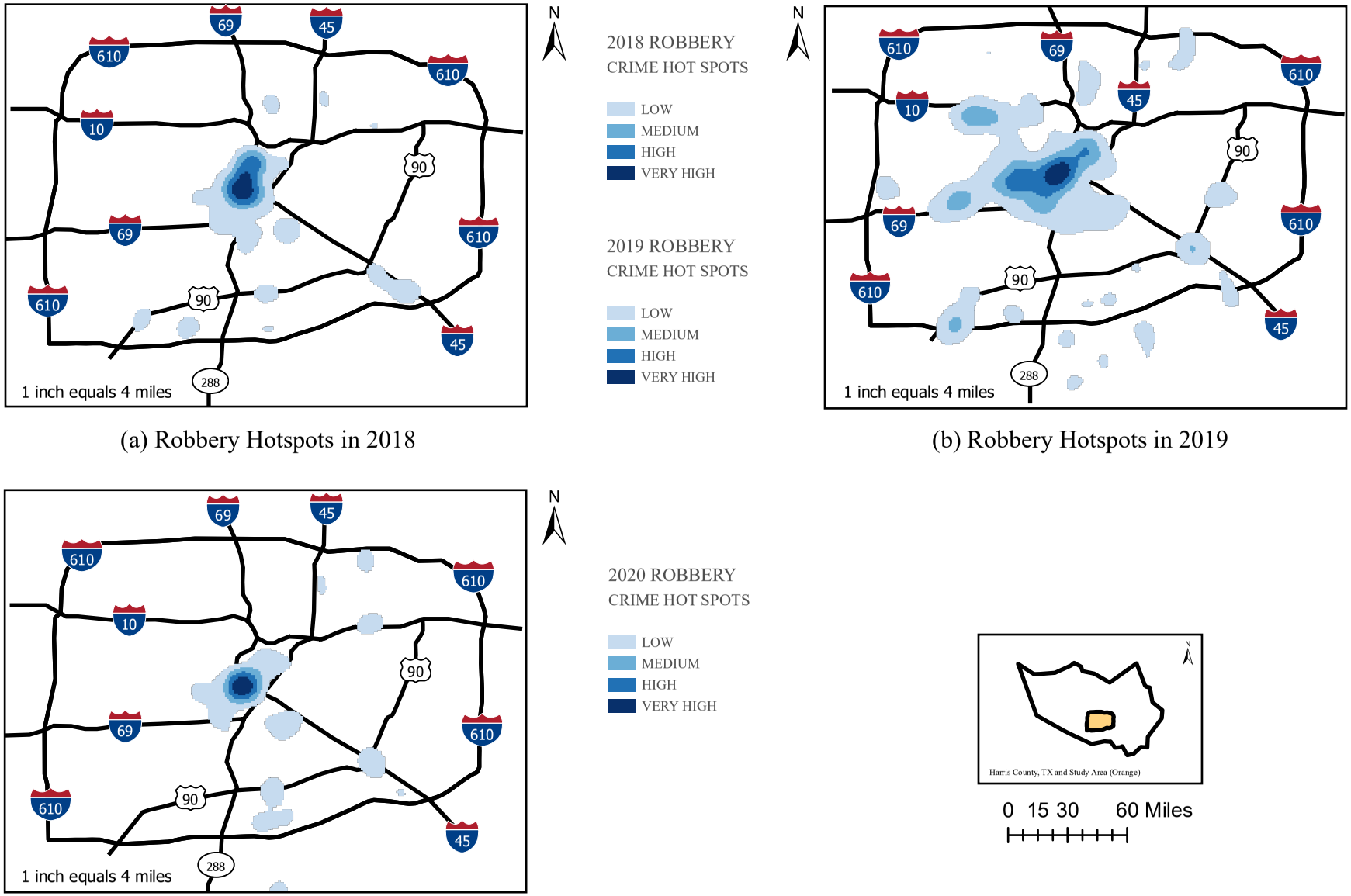
Just east of I-610 and 90, a category 3 cluster occurred on I-610 surrounded by a category 2 hotspot in 2018. In 2018 and 2019, the category 3 increased in size from 2018 to 2019 and then the category 3 disappeared in 2020 and transformed into a medium sized hotspot. This category 2 hotspot occurred in all years along 90 near I-610 and was similar in size across all three years.

There was a medium category 2 hotspot between Old Spanish and I-610 along the 90 and Main in 2018 and two small category 2 clusters south of I-610 in 2018. In 2019, the medium sized cluster increased to a medium sized category 2 cluster between the 90 and I-610. The small category 2 clusters south of I-610 in 2018 dramatically increased in size to larger category 2 clusters in 2019. In 2020, the medium sized category 2 cluster was still prevalent between the 90 and I-610. The large category 2 south of the I-610 morphed into three smaller category 2 clusters. In all years, a category 2 hotspot can be found at Wayside and Canal in the eastern section of the study area.

In 2018 and 2019, a small category 2 occurred at Fulton and Morris, but it disappeared in 2020. There were three category 2 clusters in the northeast section in 2018 and 2019, but there are just two larger category 2 hotspots in this area at Lockwood and Collingsworth and I-10 and Gregg in 2020.

4.1.3 2018-2020 Summary of Robbery Hotspots

The robberies in 2018 occurred mainly in the midtown 10H40 and downtown 1A10 districts (Figure 7). A large category 5 hotspot occurred between the border of the downtown and midtown districts on I-45. This was the same location as the 2019 and 2020 category 5 and 4 hotspots. An even larger category 4 and 3 hotspot surrounded the category 5 hotspot in the



(a) Robbery Hotspots in 2018

(b) Robbery Hotspots in 2019

(c) Robbery Hotspots in 2020

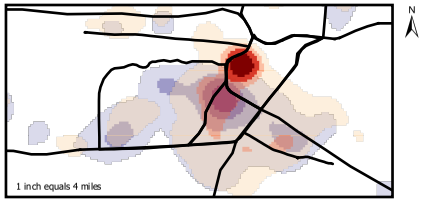
Figure 7. 2018-2020 Robbery Crime Hotspots

downtown and midtown districts in 2019. This large category 4 and category 3 hotspot extended from the central midtown to the western central downtown in 2019. A large category 5 and 4 hotspot occurred within this category 3 cluster in 2019. The remaining areas of the downtown and midtown districts experienced category 2 hotspots. A small portion of the category 2 hotspot spread into the eastern Montrose District. These hotspots were similar in size to the 2020 hotspots. A category 2 cluster occurred at Anita and Sampson in 10H50 in 2018. In 2019, this area saw a large category 2 cluster that extended into the downtown and midtown districts. In 2020, this category 2 cluster reverted to a medium sized cluster at Elgin and Sampson.

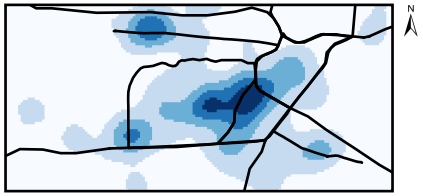
It is surprising there are no hotspots showing up along Washington Avenue in 2018. A small category 2 cluster occurred at 90/Main and Old Spanish in 15E40 in 2018. In 2019, this category 2 became a medium sized category 2 cluster with a category 3 hotspot inside it. In 2020, this pair of hotspots disappeared. There was a small category 2 cluster north of I-610 and west of 288 in 15E40 in 2018 and 2020.

A small category 2 cluster occurred at Old Spanish and La Sallette in 14D10 and 10H60 east of 288 in 2018. This cluster was not present in 2019, but it grew in 2020 to a medium sized category 2 cluster along Scott with a northern border along the 90 and a southern border along I-610. Northwest of the intersection of I-45 and 610, a large category 2 hotspot occurred between Wayside and I-610 in 11H10, 11H20, and 13D10 in 2018. In 2019, this category 2 cluster shrank and included a category 3 hotspot inside it at the intersection of 90 and I-45 and in 2020, it became a medium sized category 2 cluster.

Figure 7 summarizes the 2018-2020 robbery trends and Figure 8 shows the robbery hotspots that occurred in just one year, in two of the three years and those that occurred in all three years. The no hotspot areas were not mapped for robbery.



(a) 2018 and 2020 Robbery Hotspots

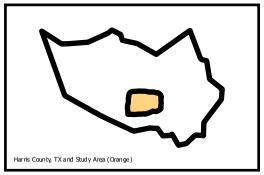


(b) 2019 Robbery Hotspots

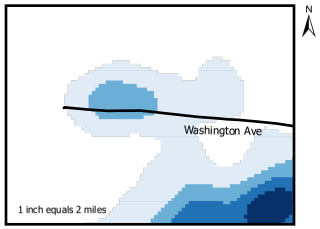
(a) and (b) 2018- 2020 Robbery Hotspots in all 3 years

2020 Robbery
Crime Hot Spots

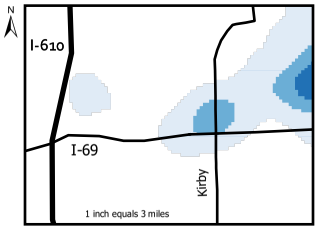
Low
Medium
High
Very High



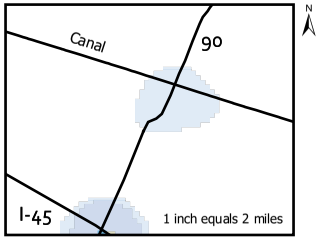
0 15 30 60 Miles



(c) 2019 category 3 and 2 cluster along Washington Ave.



(d) 2019 category 3 and category 2 hotspot at Kirby and I-69.
There is another category 2 hotspot along western I-610.



(e) 2019 category 2 burglary hotspot at Canal and 90.

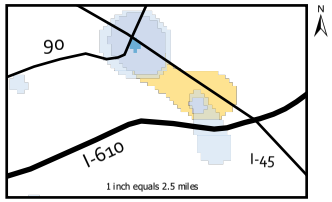
(c) - (e) 2019 Robbery Hotspots

2019 Robbery
Crime Hot Spots

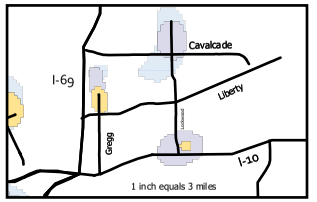
Low
Medium
High
Very High

2018 Robbery
Crime Hot Spots

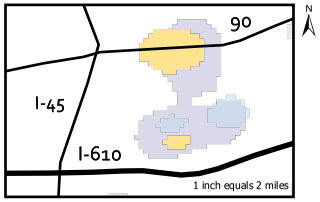
Low
Medium
High
Very High



(f) 2019 and 2020 Robbery Hotspots in the SE section.

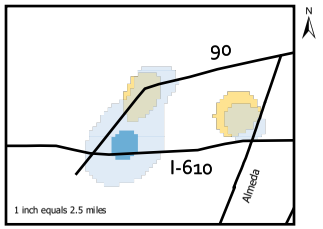


(g) 2018-2020 category 2 hotspots north of I-10 and east of I-69.

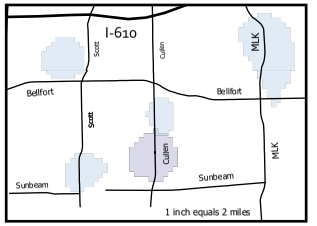


(h) 2018-2020 category 2 hotspots in the southern section.

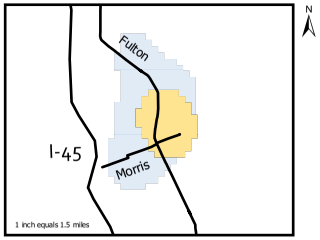
(f) - (h) Robbery Hotspots in all 3 years



(i) 2018-2020 category 3 and category 2 hotspot cluster
at the intersection of 90 and I-610.



(j) 2018-2020 category 2 hotspots in the southern section.



(k) displays the 2018 and 2019 Robbery Hotspots at Fulton and Morris.

(i.) - (k.) Robbery Hotspots in 2 years

Figure 8. Frequency of Robbery Crime Hotspots

Another small category 2 cluster exists east of I-69 in 7C20 in 2018 between Roland and Liberty. To the east of the I-45, a category 2 cluster occurred at Fulton and Luzon in 2A10 in 2018. In 2019, a medium sized category 2 occurred at Fulton and Morris and a large category 2 hotspot occurred at Cavalcade and Lockwood. There was no category 2 hotspots at Fulton and Morris in 2020. There were 2 medium sized category 2 clusters at Lockwood and the I-610 and the I-10 and Lockwood in 2020. There was a small category 2 cluster at Collingsworth and the I-69 in 2020. To the east of the I-45 and north of the I-10 in 2A10, there is a medium sized category 2 cluster on Fulton Street in 2019.

In the southern section of the study area, an extremely small category 2 cluster occurred west of Cullen, north of the I-610 and south of the 90 in 2019. A small category 2 hotspot occurred along Cullen south of the 90 and north of the I-610. Another small category 2 cluster spanned the 90 west of MLK. South of the I-610, three small and one medium sized category 2 exist. At Scott and Bellfort, a small category 2 occurred. A medium sized category 2 occurred near MLK and Bellfort. A medium sized category 2 also occurred along Telephone near the I-610. A small category 2 occurred near Bellfort and Cullen and another small category 2 hotspot also occurred at Scott and Wilmington as well.

In the southeastern section, another category 2 hotpot occurred at the I-610 and Telephone in 13D10 in 2020. Category 2 hotspot clusters occurred at Wayside and the I-45, Almeda and the I-610, Sunbeam and Cullen, Scott between Bellfort and Sunbeam, Bellfort and MLK, and at Telephone and the I-610 in 2020. In the western section of the study, a medium sized category 2 hotspot occurred near Westheimer and the I-610 in 2019.

A large category 5 robbery cluster occurred at Milam and the I-45 in 2019. This category 5 is very close to the category 5 locations in 2018 and 2020 in the northwestern midtown district. A very large category 4 cluster surrounded this category 5 cluster in 2019. It occurred in the

northwestern midtown district, southwestern to central downtown district, and the eastern Montrose district in 2019.

The central to eastern Montrose district had a large category 4 hotspot in 2019, close to the same location as the category 2 hotspot in 2020. The majority and remaining areas of the Montrose district 1A20, downtown 1A10 district, and midtown 10H40 district saw large category 3 and category 2 robbery hotspots in 2019. There was a category 3 cluster at Lake and I-69 near the Kirby District in 1A30. This category 2 spread from the downtown and midtown districts all the way to the western Upper Kirby District in 2020.

Along Washington Avenue at Durham, a large category 3 cluster occurred in 2019. There was a very large category 2 cluster that extended from Washington Avenue and the I-10 at Westcott to Sawyer in the east. This category 2 connects to the Montrose district hotspots to the south on Studemont. There were no robbery hotspots along Washington Avenue in 2018 and 2020.

There were category 5 and 4 robbery hotspots near the intersection of downtown 1A10 and midtown 10H40 districts in 2020 at the intersection of the I-45 and Brazos. A large circular category 5, 4, and 3 hotspot occurred in the northwest portion of the midtown district near the I-45. This category 5 hotspot location is the same as the 2019 and 2018 category 5 robbery hotspots. The remainder of the midtown and downtown districts saw category 3 and 2 hotspots in the southern portion of the district just like in 2018. In 2019, these category 3 and 2 hotspots intensified into large category 4 and 3 hotspots in the midtown and downtown districts. There was no occurrence of robbery hotspots along Washington Ave in the bar district in 2020, most likely due to COVID-19 and the bars being shut down.

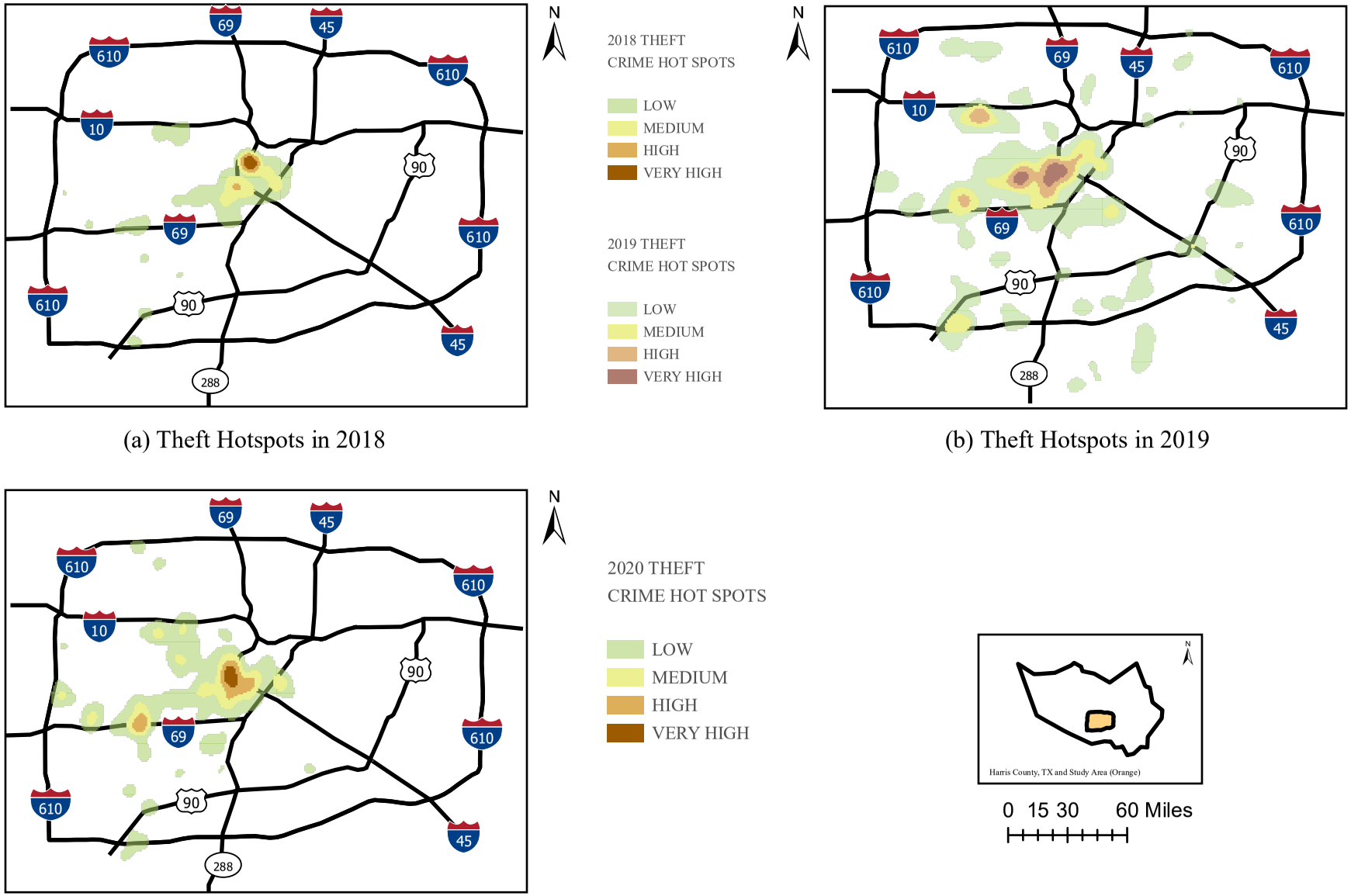
There were category 2 robbery clusters spread throughout the study area in 2020. In the northwestern section of the study area, a medium sized category 2 occurred at 19th and Ashland. In the southern portion of the study area, a large category 2 cluster occurred east of 288 and north of the I-610. This category 2 cluster was located in police beats 14D20 and 14D10 and spread from the west to the east along the I-610 for nearly two miles.

4.1.4 2018-2020 Summary of Theft Hotspots

There was a large category 5, 4 and 3 theft hotspot that intersected the downtown 1A10, midtown 10H40, and Montrose 1A20 police districts near the I-45 in 2020 (Figure 9). The category 5 hotspot was located at the intersection of Baldwin and Gray on the northwestern border of the midtown district. The midtown district experienced all three category 5 hotspots. In the northwestern midtown district, a category 5 to 4 hotspot occurred. A category 2 hotspot is found in the southwestern corner of this district as well. The downtown district also experienced category 3 and 2 hotspots that extended from the southwest to the central portion of the district. A category 4 and 3 hotspot occurred at Kirby and the I-69 in 1A30. A large category 2 hotspot connected the Montrose, downtown and midtown hotspots as well. There were two small category 3 clusters near Washington Avenue in 2020. A large category 2 hotspot extended from Washington Ave to the Montrose, downtown and midtown high theft hotspots.

A large category 2 hotspot occurred south of the I-69 and east of 288 in 2019. This cluster was located in the 10H60 and 10H50 police districts. A small category 3 cluster inside the large category 2 cluster was located near the intersection of Elgin and Sampson as well. These clusters disappeared in 2020.

Large category 5 and 4 theft hotspots occurred in the northwestern portion of the midtown district at Milam and the I-45 in 2019 near the same category 5 and 4 hotspot that occurred in 2020. This hotspot spanned the Montrose 1A20, downtown 1A10, and midtown



(a) Theft Hotspots in 2018

(b) Theft Hotspots in 2019

(c) Theft Hotspots in 2020

Figure 9. 2018-2020 Theft Crime Hotspots

districts. In 2019, category 4 and 5 hotspots emerged in the central Montrose District. The two category 5 hotspots were connected by a narrow category 4 hotspot in 1A20 in 2019 that did not occur in 2020. The central category 4 and 5 hotspot in Montrose spread out into a category 3 hotspot in 2019 that was more expansive than the category 3 hotspot in 2020 (Figure 9). The southwest corner of the downtown district contained a category 4 hotspot as well.

The remaining area of the Montrose district was a category 2 theft hotspot. Both 2020 and 2019 had category 2 clusters that covered most of the downtown, midtown, and Montrose districts and some of the Upper Kirby District. The 2019 hotspot was larger and extended southeast to the intersection of the I-45 and 288.

Category 4 and 3 clusters were found at the Upper Kirby district and the I-69 in both 2019 and 2020. Both clusters were larger in 2020. The remaining portion of the Kirby District was a category 2 cluster that expanded into the Montrose District in both years. The category 2 cluster was larger in 2019. Just north of Washington Avenue in the bar district, a category 4 hotspot occurred at the intersection of Durham and Allen in the 2A50 police precinct in 2019. A category 3 hotspot extended from Reinerman to the west to Patterson to the east along Washington Ave. A large category 2 hotspot also extended west to east along Washington Ave from TC Jester to Heights.

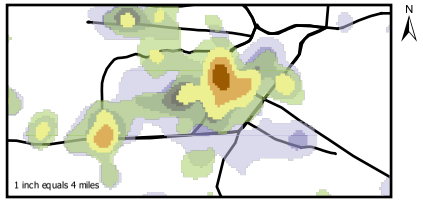
In 2020, the Washington Ave bar district had two category 3 hotspots, connected by a large category 2 cluster in police precinct 2A50, that connects to the downtown and midtown districts at Studemont. There was also a category 3 cluster at Allen and Rochow south of Washington Ave, and another to the northeast of the I-45 and the I-69. In 2019, this category 3 extended into the downtown district and was connected to the large category 5, 4, and 3 hotspots in the downtown and midtown districts (Figure 9). These category 5, 4, and 3 hotspots in the

Montrose district in 2019 diminished to small category 3 and large category 2 hotspots in 2020.

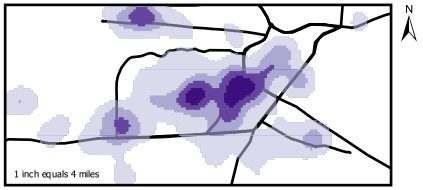
In 2019, there was one category 4 and one category 3 cluster along Washington Avenue that were surrounded by a category 2 cluster. This category 2 did not connect with the clusters in the midtown and downtown districts in 2019. There was also two small category 2 clusters near Westheimer and the I-610 in 2019 that morphed into category 3 clusters surrounded by category 2 clusters in 2020. In 2019, category 3 and category 2 hotspots occurred at the intersection of I-610 and Main/90, but the category 3 hotspot disappeared and the category 2 hotspot diminished in size in 2020.

The northeastern section of the study area had five small category 2 hotspots and one medium sized category 2 hotspot in 2019. Three of the category 2 hotspots are located on the I-10, near Wayside, Gregg and Lockwood. The final two small category 2 hotspots occurred at Gregg and Liberty, and the I-610 and Lockwood. The medium sized category 2 hotspots are located at Cavalcade and Lockwood. None of these category 2 hotspots occurred in 2020.

There are three clusters of category 2 theft hotspots in the southern portion of the study area, located north of the I-610 and south of Old Spanish between the 288 and MLK in police precincts 14D10 and 14D20. The largest category 2 hotspot spreads north and south along MLK between Old Spanish and the I-610. None of these category 2 hotspots were present in 2020 except for a very small category 2 hotspot near Calhoun and MLK. There were two small category 2 hotspots south of I-610, one at Sunbeam and Scott and the other located west of Cullen and north of Sunbeam in 2019. South of I-610 at Bellfort and MLK, there was also a category 2 theft hotspot located in police precinct 14D30. This hotspot extends north and south along MLK. None of these theft hotspots occurred in 2020. Figure 10 shows the 2019 and 2020 theft hotspots that occurred in both years, no years and the hotspots that occurred in just one year.

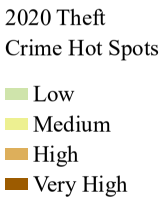


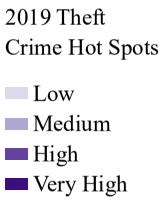
(a) 2019 and 2020 Theft Hotspots

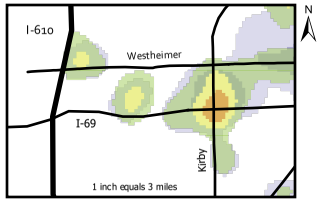


(b) 2019 Theft Hotspots

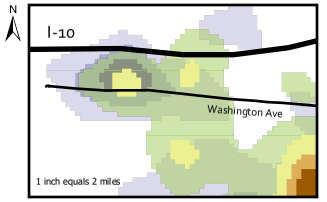
(a) and (b) 2019- 2020 Theft Hotspots in 2 years



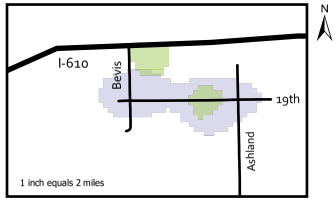




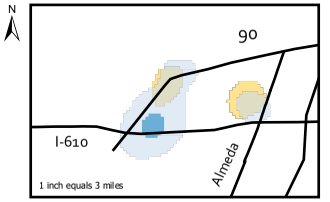
(g) 2020 category 4, 3, and 2 hotspot cluster at I-69 and Kirby. There is a 2019 category 3 and category 2 in the same location. There are two 2020 category 3 and category 2 hotspot clusters near I-69 and I-610. A 2019 category 2 occurs in the same location.



(h) 2019 category 4, category 3 and category 2 hotspot cluster along Washington Ave. There is a small 2020 category 4, 3 and category 2 in the same location. There are two additional category 3 clusters in 2020.



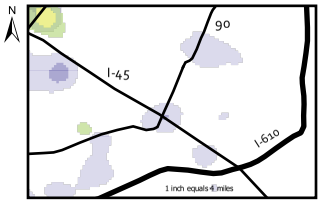
(i) 2019 and 2020 category 2 hotspots in the Northwest section.



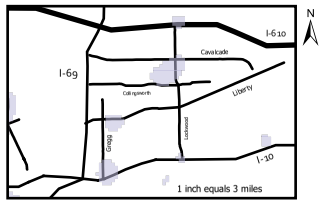
(j) Category 3 and Category 2 cluster at 90 and I-610.

(g) - (j) 2019- 2020 Theft Hotspots in 2 years

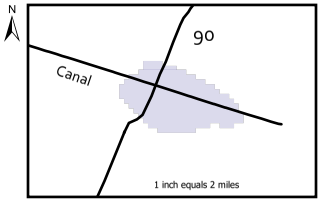
(c) 2019 category 2 hotspots in the southern section.



(d) 2019 category 2 hotspots in the SE section.

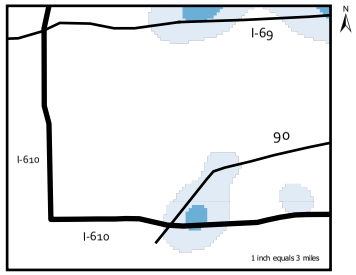


(e) 2019 category 2 hotspots near the intersection of Lockwood and Collingsworth.

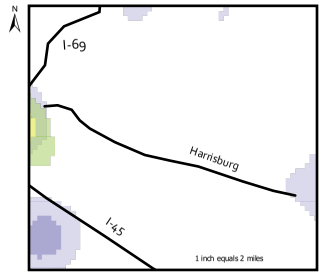


(f) 2019 category 2 theft hotspot at Canal and 90.

(c) - (f) 2019 Theft Hotspots in just one year



(k) SW section of the study with no hotspots.



(l) SE section of the study with no hotspots.

(k) and (l) Areas with no theft hotspots

Figure 10. Frequency of Theft Crime Hotspots

4.1.5 Crime Types by Year

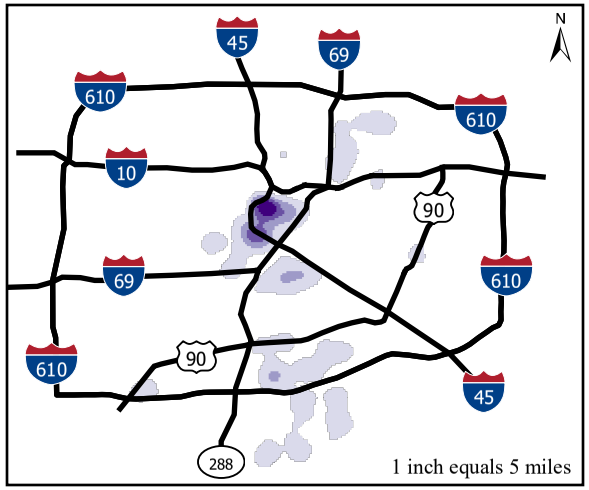
Figures 11-13 show all the crime types by year. Figure 11 shows the 2018 assault, burglary, robbery and theft crimes. Figure 12 shows the 2019 assault, burglary, robbery and theft crimes. Figure 13 shows the 2020 assault, burglary, robbery and theft crimes. In 2020, all crime types saw category 5 and 4 hotspots on the I-45 near the downtown and midtown districts. The same area experienced the category 5 and 4 clusters in 2019, but this cluster expanded into the eastern Montrose districts as well. In 2018, it was confined to a smaller area than in 2020.

4.2 2020 Land Use Types for Optimized Crime Hotspots

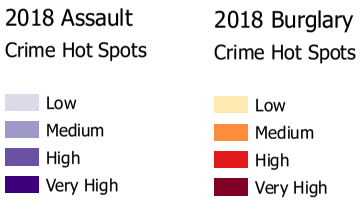
The 2020 optimized hotspots were determined for the crime types as a test of the veracity of these crime data. This test compared hotspots using two different ArcGIS data tools, Kernel Density Analysis and Optimized Hotspot Analysis. The Land Use Layer was downloaded from the COHGIS. Once the Crime Hotspots were determined, the intersect tool was used to determine the Land Use attributes of the crime hotspots areas for each crime type in 2020. Land uses, such as bars (commercial land use), were hypothesized to have contributed to crime hotspots.

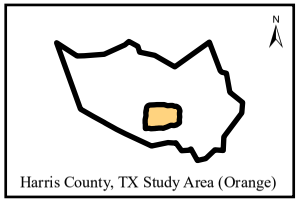
The 2020 Assault Optimized Hotspots occurred in the midtown and downtown districts, with Residential: Single-Family (48%) and Multi-Family (18%) and Commercial (4%). Another crime hotspot occurred in the southern portion of the study area where Residential: Single-Family made up 68% and undeveloped land covered 24% of this area. A similar crime hotspot in the northeastern portion of the study area was made up of Residential: Single-Family (61%) and Undeveloped Land (33%) as well.

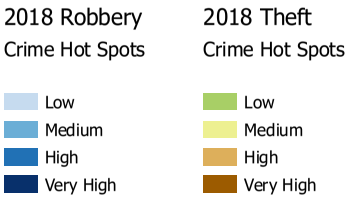
The 2020 Burglary Optimized Crime Hotspot occurred in the midtown, downtown, Montrose and part of the Upper Kirby district, consisting of Residential: Single-Family (55%), Multi-Family (17%), Undeveloped land (17%), Commercial (5%), and Industrial (3%). At US 90

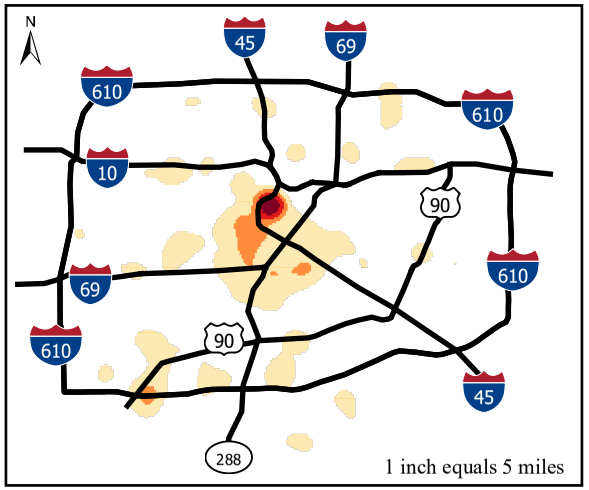


(a) 2018 Assault Hotspots

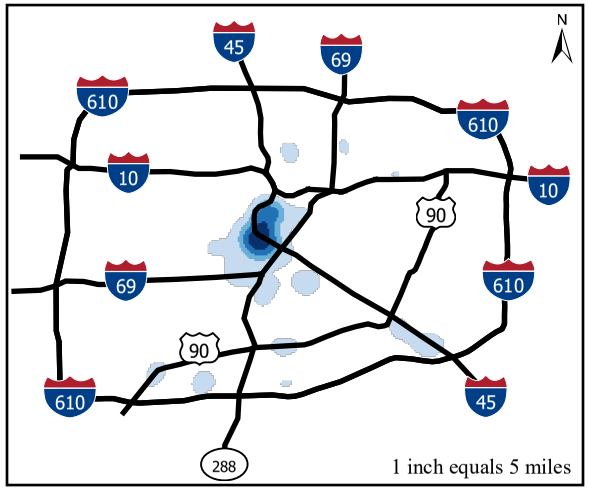




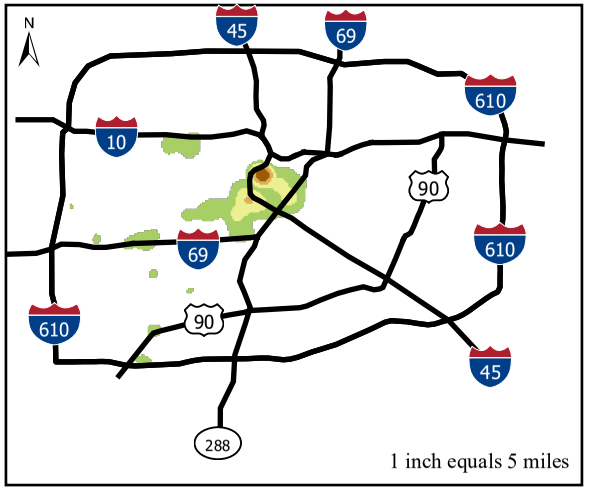




(b) 2018 Burglary Hotspots

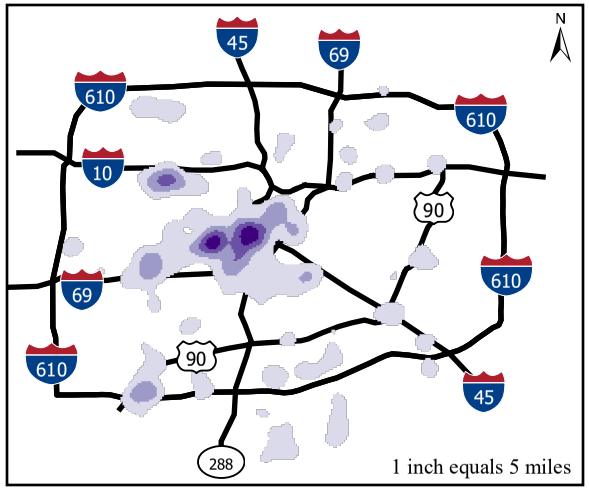


(c) 2018 Robbery Hotspots

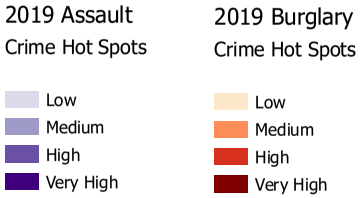


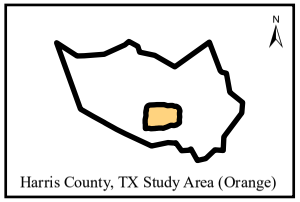
(d) 2018 Theft Hotspots

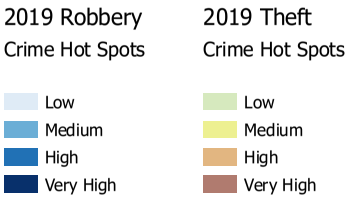
Figure 11. 2018 Crimes by Type

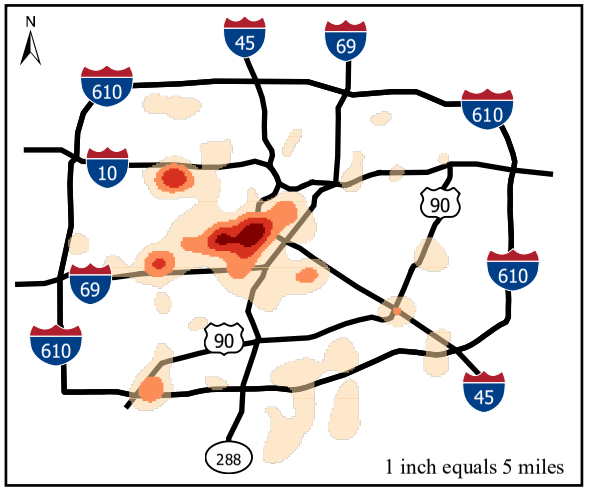


(a) 2019 Assault Hotspots

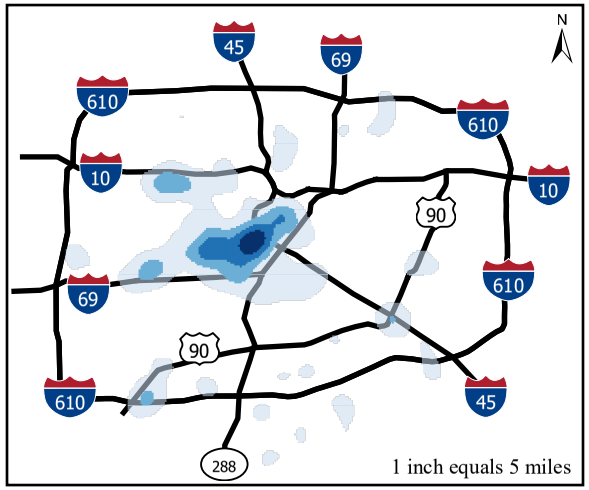




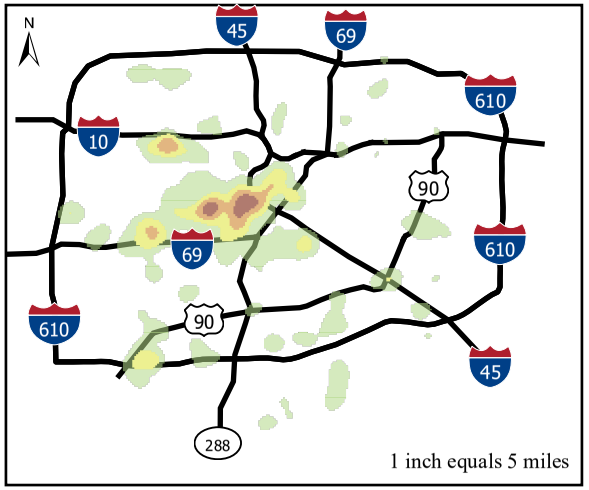




(b) 2019 Burglary Hotspots

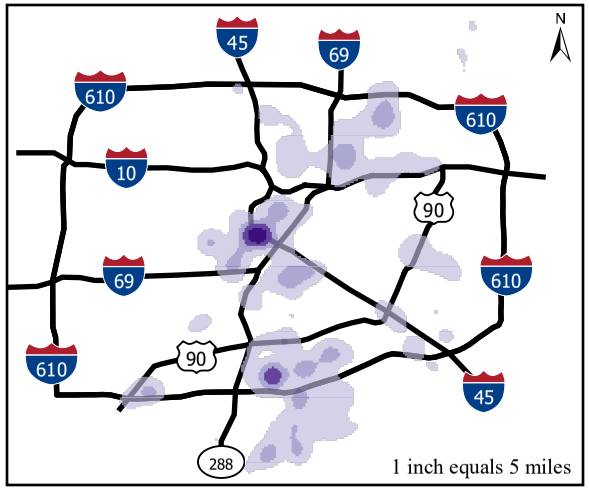


(c) 2019 Robbery Hotspots

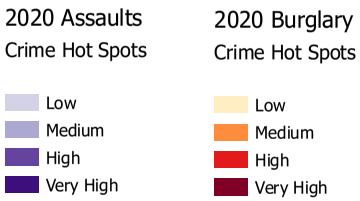


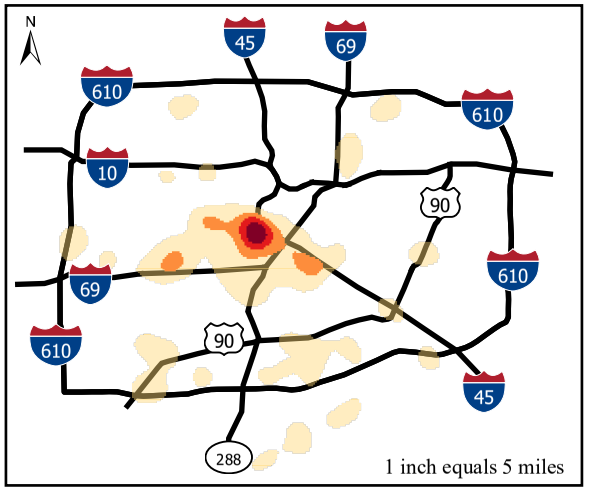
(d) 2019 Theft Hotspots

Figure 12. 2019 Crimes by Type

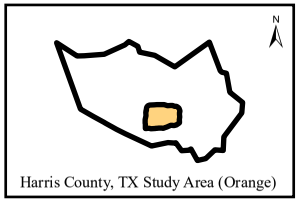


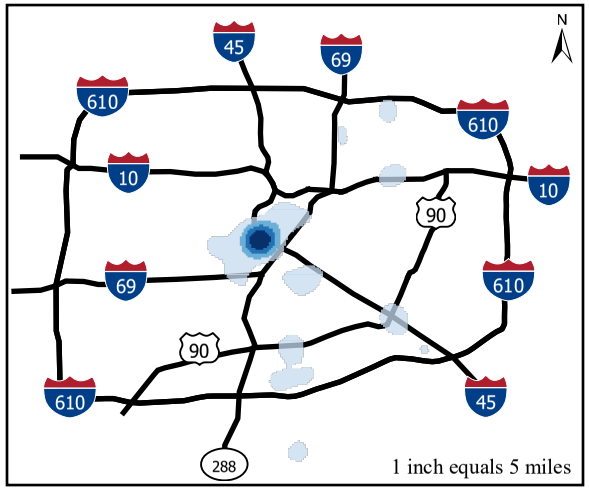
(a) 2020 Assault Hotspots



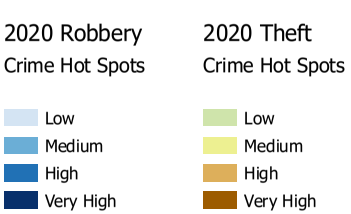


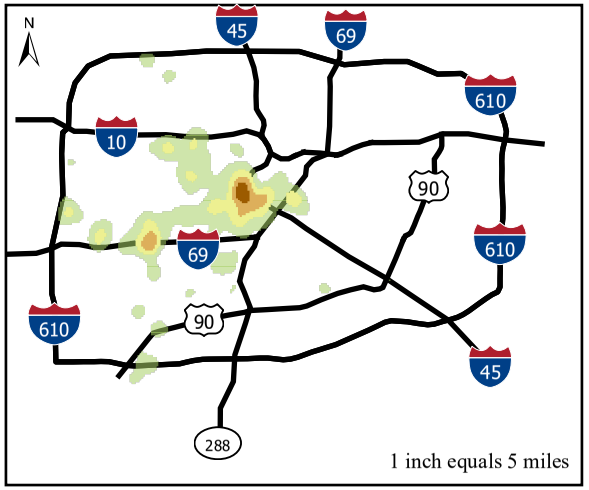
(b) 2020 Burglary Hotspots





(c) 2020 Robbery Hotspots





(d) 2020 Theft Hotspots

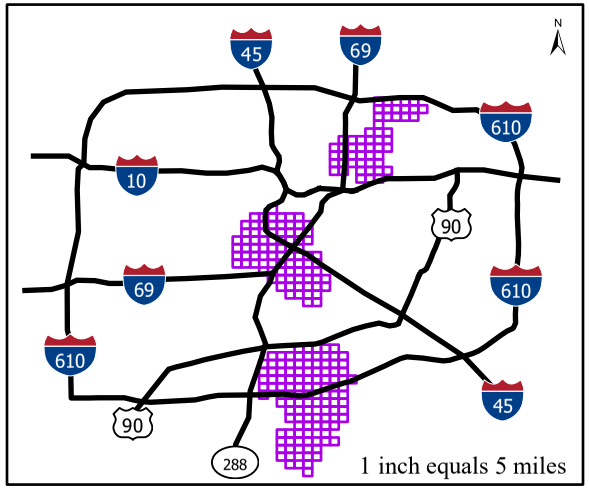
Figure 13. 2020 Crimes by Type

and the I-610, another crime hotspot occurred Single-Family (75%), Commercial (11%), and Undeveloped land (6%). The 2020 Robbery Optimized Crime Hotspots occurred in the downtown and midtown districts, with predominately Residential: Single-Family (47%), Multi-Family (29%), and Undeveloped land (20%).

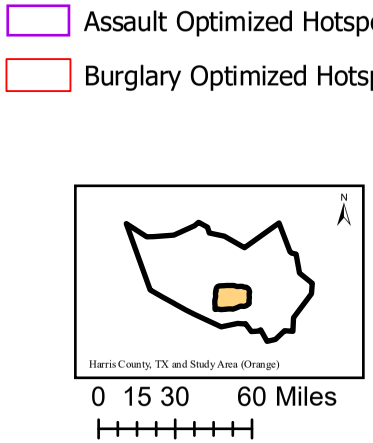
The 2020 Theft Optimized Land use occurred in the downtown, midtown, Montrose, and Kirby districts. This large crime hotspot extended into the bar district along Washington Avenue. The land use types for this crime hotspot included Residential: Single-Family (55%), Multi-Family (17%), Commercial (5%), and Industrial (3%). The second theft crime hotspot occurred in the western portion of the Kirby District. The land use types for this crime hotspot included Residential: Single-Family (67%) and Multi-Family (25%) and another theft hotspot located along I-610 in the western section of the study comprised of Multi-Family (54%), and Single-Family (38%) residential land uses.

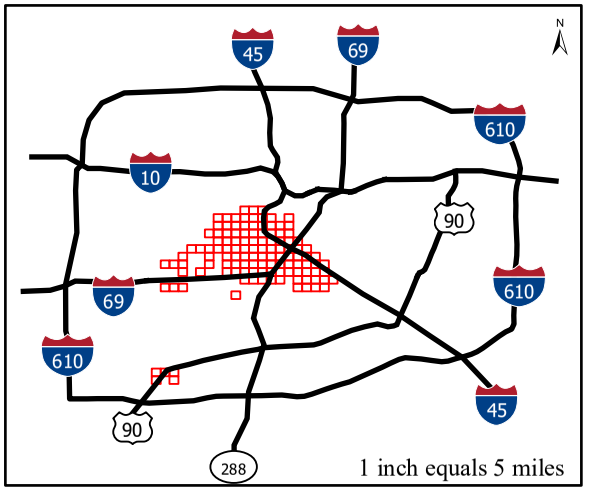
Figure 14 shows the 2020 optimized hotspots for assaults, burglaries, robberies and theft. All four crime types show optimized hotspots in the downtown and midtown districts in 2020. Figure 15 shows land use in the downtown and midtown districts. Ten land use categories occur in this part of the study area.

The 2020 Assault Optimized Hotspots occurred mainly in the downtown, midtown and Montrose districts. The northeastern section saw an area of Gi Bin level 3 assault and the southern section of the study saw a large Gi Bin level 3 assault south of US 90, east of 288 and south of the I-610. 2020 Burglary was confined to the downtown, midtown, Montrose and Upper Kirby Districts except for a very small area at US 90 near the Astrodome. 2020 robbery was confined to just a small cluster at the downtown, midtown, and Montrose districts. 2020 theft occurred in a large area generally south of the I-10 and north of the I-69 and east of the I-610. The highest theft cluster was at the downtown, midtown, Montrose, Kirby and Washington Ave.

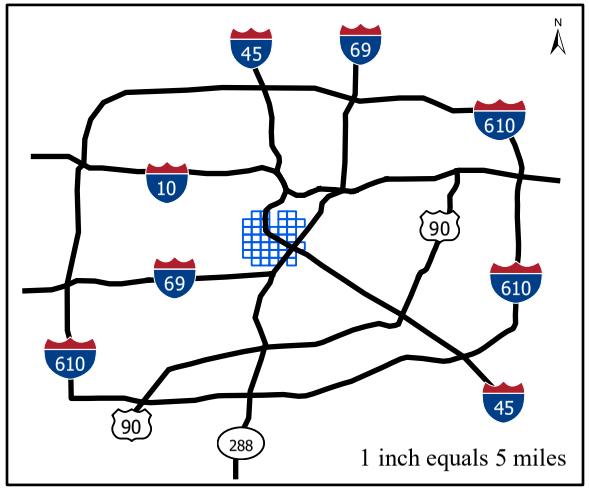


(a) 2020 Assault Optimized Hotspots

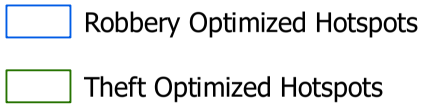


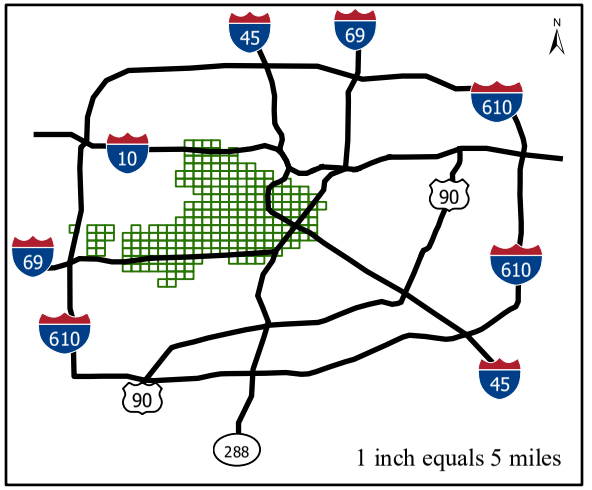


(b) 2020 Burglary Optimized Hotspots



(c) 2020 Robbery Optimized Hotspots





(d) 2020 Theft Optimized Hotspots

Figure 14. 2020 Optimized Crime Hotspots

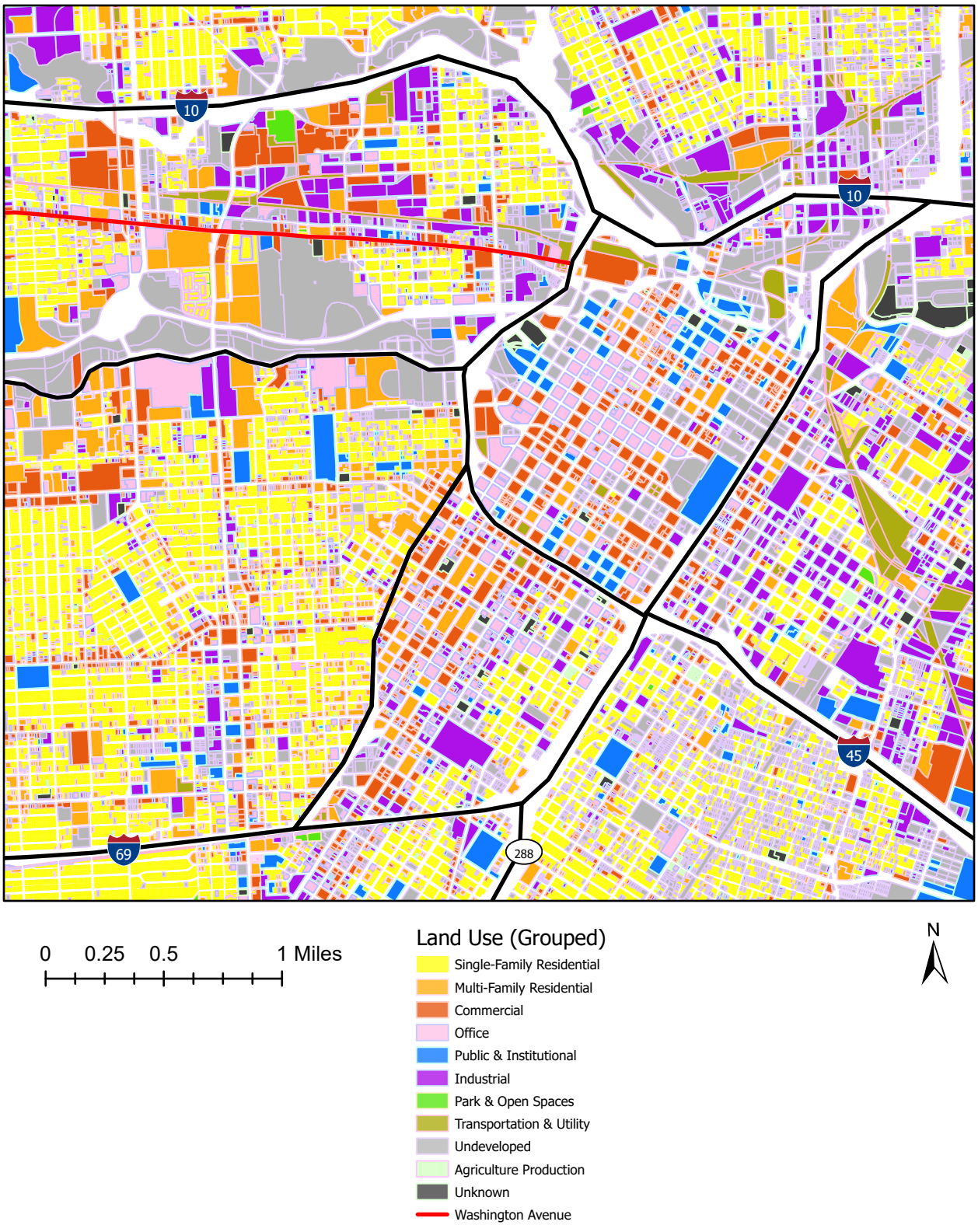


Figure 15. Downtown and Midtown District Land Uses

4.3 Crime Statistics Before and After Natural Disasters

One month after Tropical Storm Beta in September 2020, Assault decreased by 63 occurrences and Burglary decreased by 73 occurrences (Table 3). In September 2020, Robbery increased by 18 occurrences and Theft increased by 23 occurrences. Assault in October 2020 saw 32 more occurrences than in August 2020 and 95 more occurrences than in September 2020.

Burglary in October 2020 had 29 less occurrences than in August 2020 and 44 more occurrences in October 2020 than in September 2020 (Table 3). Robbery in October 2020 increased by 2 occurrences than in August 2020 and fell by 16 occurrences in October 2020 compared to September 2020. Theft in October 2020 saw 93 more occurrences than in September 2020 and 116 more occurrences than in August 2020 (Table 3).

Table 3. Crime Statistics Before and After Tropical Storm Beta

Crime Type	August 2020	% Change	September 2020	% Change	October 2020
Assault	1075	- 6	1012	+ 9	1107
Burglary	415	- 18	342	+ 13	386
Robbery	182	+ 10	200	- 8	184
Theft	798	+ 3	821	+ 11	914

Source: Houston Police Department

Tropical Storm Imelda occurred in September 2019. From August 2019 to September 2019, assault decreased by 8% (Table 4). October 2019 Assault saw a 3% decrease in crime compared to August 2019. From August 2019 to September 2019, burglary decreased by 2%. October 2019 Burglary saw a 11% decrease in crime type compared to August 2019. From August 2019 to September 2019, Robbery decreased by 9%. In October 2019, Robbery also decreased by 9% compared to August 2019. Theft in September 2019 decreased by 10% compared to August 2019. Theft in October 2019 decreased by around 11% compared to August 2019 (Table 4).

Table 4. Crime Statistics Before and After Tropical Storm Imelda

Crime Type	August 2019	% Change	September 2019	% Change	October 2019
Assault	1112	- 8	1021	- 5	1076
Burglary	477	- 3	464	- 8	423
Robbery	252	- 10	228	0	228
Theft	1499	- 10	1342	- .02	1338

Source: Houston Police Department

Hurricane Harvey made landfall on the Texas coast on August 27th, 2017 and the percent changes for crime before and after are shown in Table 5. The increases and decreases of crimes in specific months are compared to July 2017. For example, there were 24 less assault crimes in August 2017 compared to July 2017.

Table 5. Crime Statistics Before and After Hurricane Harvey

Crime Type	July 2017	% Change	August 2017	% Change	September 2017	% Change	October 2017
Assault	375	- 6	351	- 3	341	+ 8	369
Burglary	419	+ 35	564	- 28	408	- 5	388
Robbery	231	- 13	200	- 19	162	+ 47	238
Theft	2226	- 10	2013	- 13	1754	+ 16	2027

Source: Houston Police Department

4.4 Bus Hotspot Locations and 2020 Crime Hotspot Locations

There are 4,106 Metro Bus Stops within the I-610 Loop study area and just less than 10% (307) of these bus stops fall within the downtown and midtown districts that contain the police precincts 1A10 and 10H40. Kernel Density analysis on the bus stop locations showed category 5, 4, 3, and 2 densities of bus stops within the downtown and midtown districts. The downtown district has a large category 5, 4, 3 covering most of the central portion of the downtown district. The category 5, 4 and 3 hotspots falls in the downtown 1A10, midtown 10H40, and 1A20 Montrose districts. Appendix C displays the kernel density analysis on the Metro Bus Stops.

The northern to central portion of the midtown district has a category 4 and 3 density of bus stops. The southern portion of the midtown district has a category 2 density of bus stops. The downtown and midtown districts are the only places in the study area with category 5, 4, 3 densities of bus stops. The remainder of the study area has category 2 densities. These category 2 densities of bus stops occur within 3-5 miles of the category 5,4,3 densities located within the downtown and midtown districts.

This study also found that 2018-2020 crime type category 5 and 4 hotspots mainly occurred in the downtown and midtown districts. There is a connection between very high (category 5) and high (category 4) crime type hotspots and very high (category 5) and high (category 4) bus stop locations. Appendix A shows the category 5 and category 4 densities of bus stops occurring in the downtown and midtown districts. This is the same area that experiences the category 5 and category 4 hotspots of Assault, Burglary, Robbery and Theft.

4.5 2020 Edge Effects Test of Data: July-December 2020

4.5.1 2020 Assault Boundary Hot Spots

There was no category 5, 4, and 3 assault hotspots that occurred outside the I-610 boundary. A small category 2 cluster occurs north of the I-610 at the intersection of Cross Timbers and the I-45 in police precincts 3B40 and 3B50. Another small category 2 cluster occurred at Cross Timbers and the I-69 in police precinct 7C30. A very small category 2 cluster occurred at Homestead and Tidwell in police precinct 8C10. Beyond the western boundary of the I-610, a larger category 2 cluster occurred at Rampart and Gulfton in 17E10. At Westheimer and the I-610, a small category 2 cluster can be found. South of the I-610, a large category 2 hotspot occurred on Cullen Street in police precinct 14D20. Southeast of the I-610, a small category 2 cluster occurred at Rockhill and Broadway in police precinct 13D20 and nearby at Howard and

the I-45, a very small category 2 cluster can be found in police precincts 13D20 and 11H30.

4.5.2 2020 Burglary Boundary Hot Spots

North of the I-610 study area, there was a small category 2 cluster near the intersection of Bennington and the I-69 in police precinct 7C30. Just north of this intersection, a smaller category 2 cluster occurred at Aldine Westfield and Jensen in police precincts 7C30, 8C10, and 7C20.

A very large category 2 burglary hotspot occurred to the north and northwest of the study area, between Wirt and Fulton in police precincts 3B50, 3B40, 3B30, 3B10, 5F10, 2A60, 2A30, and 2A20. The southern boundary extends well south of I-610 all the way to Fulton. Northwest of the I-610 study area, a small category 3 cluster exists within this massive category 2 cluster at the intersection of 34th and Mangum in police precinct 3B10. North of this category 3 cluster, another small category 3 cluster surrounded by a large category 2 cluster occurred at Antoine and Tidwell in police precinct 3B10.

An extremely small category 2 cluster was found at Antoine and the I-10 west of the study area in police precincts 5F10 and 18F10. Another large category 2 cluster extends from Mobud and Braewick to the intersection of Briar Hollow E and Briar Hollow N in police precincts 17E10, 18F20, 1A50 and 1A40. Just outside the I-610 west of the study area, a small category 4 cluster was located at Sage and Alabama in police precinct 18F20. This category 4 was surrounded by a large category 3 cluster that extends from Yorktown and Schumacher to Post Oak and Post Oak Park across the I-610.

A small category 2 cluster was found at Braeswood and Braesmont southwest of the study area boundary in police precinct 15E10. South of the I-610 study area, two small category 2 clusters extend as far as Bellfort and Cullen in police precincts 14D20 and 14D30. From the

southeast, two category 2 clusters extend as far as Sunbeam in police precincts 14D20 and 14D30 and Winfree (13D10, 11H20, and 11H10). There is also a category 3 cluster surrounded by a category 2 cluster located southeast of the I-610 study area. Similar to the other crime types, there were no burglary hotspots located to the east of the I-610 study area.

4.5.3 2020 Robbery Boundary Hot Spots

Outside the northern I-610 boundary, there is a medium sized category 4 robbery hotspot at the intersection of Cross Timbers and the I-45. This category 4 hotspot is surrounded by a category 3 hotspot in police precincts 3B40 and 3B50 and a category 2 hotspot surrounds the entire category 3 hotspot as well. There is also a large category 2 hotspot at I-69 and Keeland in police precincts 3B40 and 3B50 and a very small category 2 cluster occurred at Tidwell and Homestead in police precincts 7C30 and 8C10.

Northwest of the I-610 boundary, a very small category 3 cluster can be found at the 290 and Kingswood police precinct in 3B10. A large category 2 cluster also occurred in this police precinct 3B10 as well. Southwest of the I-610 study area, a category 5 can be found at Rampart and Clarewood in police precinct 17E10. This category 5 robbery cluster is surrounded by category 4 and 3 hotspot clusters. There is also a category 2 cluster that extends northeast of the category 5 and category 4 clusters and a small category 3 cluster occurred inside this category 2 at the intersection of Mccue and Alabama in the Galleria area of police precinct 18F20.

A category 2 robbery hotspot extended south of the I-610 between Scott and Jutland to Airport in police precinct 14D20. A small category 3 cluster surrounded by a category 2 cluster can be found at Bellfort and Glencrest in police precincts 13D20 and 11H30. A medium sized category 2 hotspot can be found at Laura Koppe and the I-69 to the north of the I-610. This category 2 cluster extends north to Parker and south to Bennington along the I-69. Finally, a

small category 2 hotspot can be found at the intersection of Tidwell and Homestead in police precincts 7C30 and 8C10.

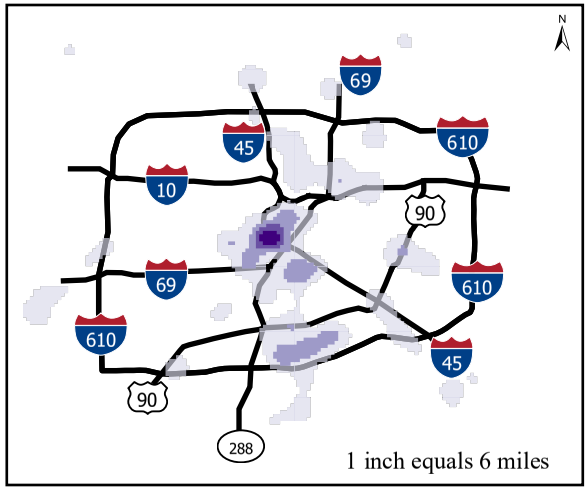
4.5.4 2020 Theft Boundary Hot Spots

North of the I-610 study area, a very small theft cluster can be found at I-45 and Cross Timbers in police precincts 3B40 and 3B50. Northwest of the I-610 study area, a very small category 2 cluster can be found at 290 and 34th street in police precinct 3B10. West of the study area near I-610, small category 5 and category 4 theft hotspots can be found at the intersection of Westheimer and the I-610. Medium sized category 3 and category 2 theft hotspots surround the category 5 and 4 hotspot in police precincts 18F20, 17E10, and 1A50.

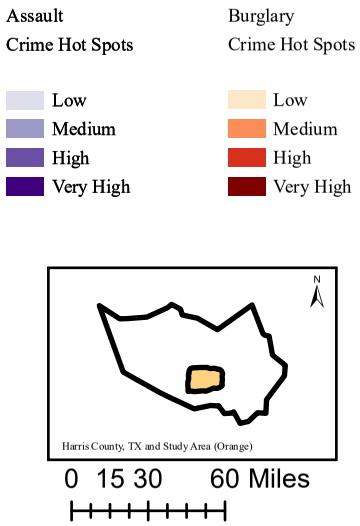
A small category 2 cluster can also be found at the intersection of Hillcroft and Clarewood in police precinct 17E10. Finally, another small category 2 cluster extends south of the I-610 study area to Bellfort near US 90/Main in police precinct 15E40.

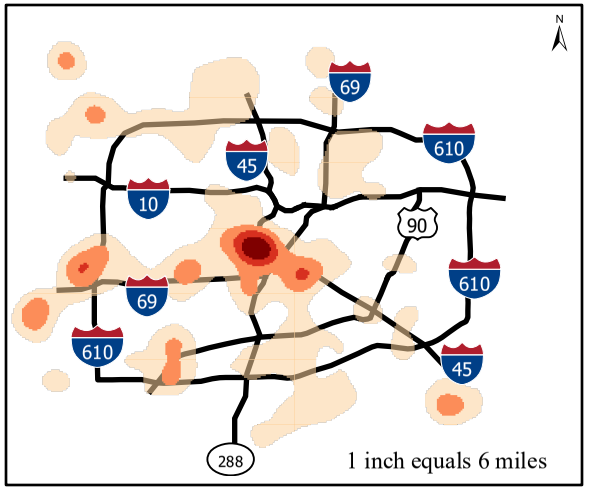
Figure 16 shows the 2020 edge effect crimes of assault, burglary, robbery and theft. Appendix B shows the top 50 bars locations in Houston, TX. These data was obtained from Google maps. The majority of these bars are located along Washington Ave in the bar district. Several others occur in the downtown and midtown districts. There is a small cluster of these bar locations near the I-45 in close proximity to the downtown and midtown districts. This area saw the category 5 and 4 hotspot clusters for all crime types. There is also a small cluster of bars in the Upper Kirby district near the intersection of the I-69 and Kirby Drive and this area saw a small category 3 hotspot cluster for most of the crime types as well.

The final chapter that follows reviews the successes, challenges and failures of this study and provides a discussion of the implications of the study for law enforcement and future research on crime.

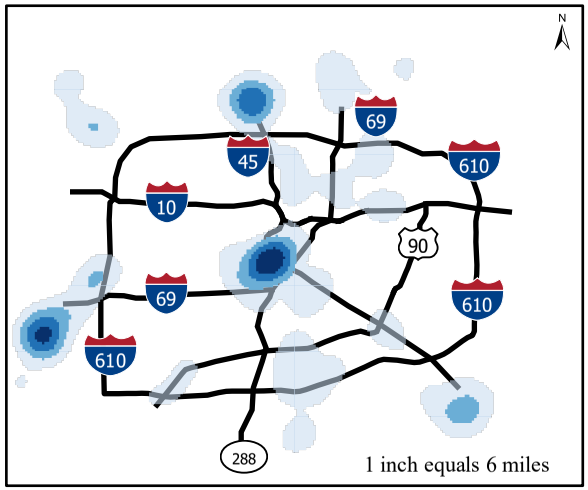


(a) 2020 Assault Edge Effects

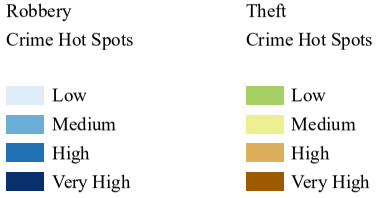


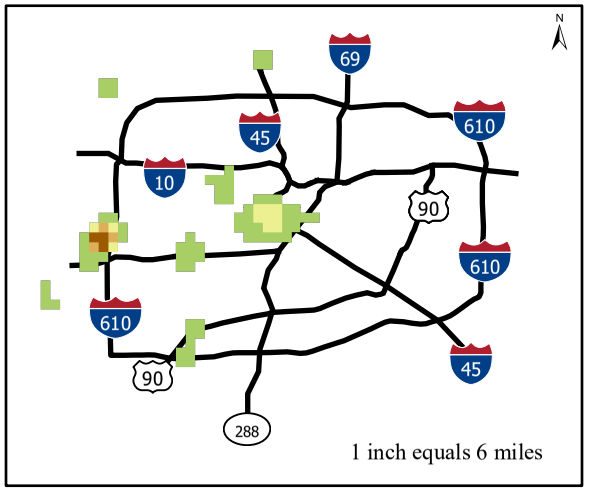


(b) 2020 Burglary Edge Effects



(c) 2020 Robbery Edge Effects





(d) 2020 Theft Edge Effects

Figure 16. July-December 2020 Edge Effects

Chapter 5 Conclusions

Houston, Texas has one of the highest rates of crime in the nation. To address this threat, law enforcement must understand the spatial and temporal patterns of crime, as well as what variables are related to criminal activity. This project sought to visualize the distribution of crime types in downtown Houston between 2018 and 2020 to enable law enforcement agencies to better respond to disturbances in the region. While the area was bounded by the inner I-610 loop, edge effects were taken into consideration. The particular crime types analyzed were assault, burglary, theft, and robbery hotspots in the inner I-610 Houston, Texas region. Additional variables included in the study, which were identified through the literature review, included land use type and proximity to bus stations. An exploratory component of the project looked at crime rates before and after natural disasters, namely a tropical storm or hurricane.

Crime location data was supplied by the Houston Police Department Crime Statistics website. The data on land use type and bus station location were provided by the City of Houston GIS. Once all the data was cleaned, aggregated, and uploaded to ArcGIS Pro, kernel density analysis and hot spot analysis were used to visualize crime hotspots. The crime addresses were geocoded using CDX WinZip and ArcGIS Pro Geocoder to facilitate further spatial analysis and visualization. A number of visualizations were created to show the target audience how crime type and location changed over time. Analysis was conducted looking at the relationship between crime, bus stop locations, and land use types.

The midtown, downtown and Montrose districts experienced the most category 5, 4 and 3 crime hotspots for the four crime types for all three years of the study. The highest density of bus stops were located within the downtown and midtown districts of the study area. The land use type that represented the largest areas (in acres) for the optimized hotspots was mainly single-

family: residential. Although the largest land use type within these Gi Bin +3 crime hotspots was single-family, this does not necessary mean that single-family units are the cause of the crime hotspots.

Generally, crime was more prevalent and more widespread in 2019 than in 2018 and 2020. Crime trends showed category 5 and 4 hotspots spreading into the Montrose district and category 3 and category 2 hotspots expanding to the Washington Avenue bar district in 2019. For some of the crime types, this expansion was not evident in 2018 and 2020. Crime may not have been as prevalent in 2020 because of the closures, curfews and Covid pandemic lockdown of 2020. This could possibly explain, for example, why assault was present along Washington Avenue in 2019 and not in 2020.

5.1 Research Questions and Summary of Findings

This study addressed the following research questions in the inner I-610 Houston, TX:

1) Where are crime hot spots located within the city of Houston, TX?

2) What types of crime constitute different hot spots?

3) What are the crime trends for the city over time (2018-2020, annual and seasonal)?

4) What factors, variables, or indicators have a spatial relationship with crime hot spots (namely bars, other land uses)?

5) Does crime increase or decrease before and after natural disaster such as tropical storms and hurricanes?

5.1.1 Crime hot spots located within the city of Houston, TX?

The highest concentration of crime hotspots occurred in the downtown and midtown districts of Houston, TX. This trend was found across all crime types. The category 5 and category 4 crime hotspots were found near the intersection of the downtown, midtown and

Montrose districts. Category 3 clusters were also found at I-69 and Kirby and along Washington Avenue in the bar district and southeast of I-69 and 288, at the intersection of Sampson and Elgin.

5.1.2 What types of crime constitute different hot spots?

The category 5 and 4 crime hotspots occurred mainly in the downtown and midtown districts for all 4 crime types. Most of the downtown and midtown districts experienced at least category 3 hotspots. Category 3 hotspots were also found along Washington Avenue. A large area of category 2 hotspots for all crimes were found in the southern section of the study area, south of US 90 and east of 288 near I-610. There were a smaller number of category 2 hotspots for each crime type in the northeast, southwest, and the eastern section of the study. The upper Kirby district in the western portion of the study also experienced category 2 hotspots with a few category 3 hotspots at Kirby and I-69.

5.1.3 Crime trends for 2018-2020

5.1.3.1 Assault Crime Hotspots

In all three years, there was category 5 and 4 clusters near the intersection of the midtown and downtown districts on I-45. An additional category 5 and a category 4 cluster popped up in the Montrose District in 2019. The northern section north of I-10 and these areas east of I-69 saw category 3 and 2 clusters in all 3 years. The southern section south of US 90 and east of 288 contained category 3 and 2 clusters in all three years. The intersection of I-610 and US 90 experienced category 3 and 2 clusters in all three years as well.

Four areas saw hotspots in this just one year (2019). For example, category 4, 3 and 2 hotspots occurred at Kirby and Washington in 2019, but not in 2018 or 2020. At Kirby and I-69 in the upper Kirby district, a category 3 hotspot and large category 2 hotspot occurred in 2019

and was connected to clusters in the Montrose District. The northwest section along Nineteenth Street experienced a category 2 cluster in 2019 and at Almeda and I-610, a large category 2 cluster occurred in 2019. Category 2 clusters occurred in two of the three years at Bellfort and MLK, Canal and US 90, and along Holcombe north of US 90.

5.1.3.2 Burglary Crime Hotspots

All three years experienced category 5, 4 and category 3 burglary hotspots near the intersection of the downtown and midtown districts. The 2019 category 5 and 4 hotspots spread into the Montrose District. A large category 2 covered a majority of the downtown, midtown and Montrose districts in all three years. The upper Kirby district saw category 3 and category 2 hotspots in all three years. Canal and 90 experienced a category 2 hotspot in all three years. Washington and Kirby experienced category 2 hotspots in all three years. Lockwood and Collingsworth in the northern section of the study area saw category 2 hotspots in all three years and the southern section south of US 90 and east of 288 experienced numerous category 2 clusters in all three years. The areas near the I-610 and US 90 intersection experienced category 3 and category 2 hotspots in all three years as well.

Three unique areas in the south-central, southwest and northern section north of Fulton and Morris experienced small category 2 clusters in 2019. The I-45 at US 90 and the I-45 and I-610 experienced category 2 clusters in two of the three years. The I-10 and US 90 saw small category 2 clusters in two of the three years, and Fulton and Morris also experienced small category 2 clusters in two of the three years.

5.1.3.3 Robbery Crime Hotspots

All three years saw a category 5 and category 4 hotspot next to the I-45 as it crossed the downtown and midtown districts. In 2019, large category 3 and 4 clusters expanded and covered

a majority of the downtown, midtown and Montrose districts. The southeast section on I-45 at US 90 and the I-610 saw category 2 clusters in all three years, and the northern section experienced small category 2 clusters north of I-10 and east of I-69 in all three years. The southern section north of I-610 and east of I-45 saw large category 2 hotspots in all three years.

The I-610 and US 90 intersection and I-610 and Almeda saw large category 2 and a small category 3 cluster in two of the three years respectively, Fulton and Morris saw a category 2 cluster in two of the three years and south of the I-610 along Cullen, two small category 2 clusters occurred in two of the three years. Washington Ave experienced a large category 2 and a category 3 cluster in 2019 that did not occur in the other two years. Similarly, the upper Kirby district saw a category 3 cluster within a large category 2 cluster that extended to the Montrose district in 2019, but not in the other two years. The upper Kirby district hotspot did not occur in the other two years. The area near Canal and US 90 saw a category 2 cluster in 2019 as well, but not in the other two years.

5.1.3.4 Theft Crime Hotspots

Both 2019 and 2020 saw category 5 and 4 hotspots near the intersection of the downtown, midtown and Montrose districts. In 2019, a large category 4 cluster covered a majority of the downtown, midtown and Montrose districts. This same region experienced a category 2 cluster in 2020. In both years, category 3 and 2 clusters occurred at Kirby and I-69. Two category 2 clusters occurred north of I-10 and just east of I-610 near Westheimer in the western portion of the study area. Washington Avenue experienced a category 3 cluster and a large category 2 cluster in both years. At the I-610 and 90, category 2 and 3 clusters occurred in both years. In the northwest section, category 2 clusters were present along 19th in both years. South of 90 and east of 288 in the southern section, category 2 clusters were found only in 2019.

Similarly, category 2 clusters occurred along the I-45 and at Canal and US 90 in the southeastern section of the study area in 2019, but not in the other years.

These findings suggest that law enforcement should expect to see the highest concentrations of all crime types near the intersection of the midtown and downtown districts near I-45. The eastern Montrose district also showed high densities for almost every crime type. The Washington Ave bar district showed category 3 and 2 hotspots for all crime types. The upper Kirby district at Kirby and I-69 also displayed category 3 and 2 hotspots for almost every crime type. The allocation of more police resources and potential policy changes by city officials could help to reduce the crime levels of these areas in the future.

5.1.4 2020 Land Use Types and Optimized Crime Hotspots

One objective of the project was to better understand the relationship between land use type and crime hot spots. This was done using Kernel Density Analysis and Optimized Hotspot Analysis. The land use type attributes were selected from within the optimized crime hotspots that experienced Gi Bin +3. This represents a 99% confidence level as to whether or not a crime hotspot is present.

The sum of the area (in acres) of each land use type for each optimized crime hotspot was calculated. The discovery that a certain land use type accounted for a majority of the total area of the optimized Gi Bin level +3 does not necessary mean that land use is the cause of the crime hotspot. The next few paragraphs report the area percentages of each of the land use types calculated from total land use acres.

The 2020 Assault Optimized Hotspots occurred in the midtown and downtown districts, which were primarily single-family housing (48%). Another crime hotspot occurred in the southern portion of the study, which was comprised of single-family housing (68%) and

undeveloped land (24%). In the northeastern section of the study area, another crime hotspot was dominated by single-family housing (61%) and undeveloped land (33%). Thus, the study suggests that single-family housing made up the largest land area in acres for assault hotspots. Just because single-family housing units accounted for the largest land use, does not mean that single-family housing units are the cause of crime hotspots, but rather that this land use is disproportionately represented in the assault Gi Bin +3 areas.

The 2020 Burglary Optimized Crime Hotspots occurred in the midtown, downtown, Montrose and part of the upper Kirby district. The land use associated with these crime hotspots were single-family housing (55%), multi-family housing (17 %), undeveloped land (17%), commercial (5%) and industrial (3%). Another crime hotspot occurred in the southwestern portion of the study at US 90 and the I-610. The land use for this crime hotspot are single-family housing (75%), commercial (11%), and undeveloped land (6%). Again, single-family housing represented the largest land use in the burglary Gi Bin +3 crime hotspots.

The 2020 Robbery Optimized Crime Hotspots occurred at the intersection of the downtown and midtown districts. This crime hotspot spilled into the eastern portion of the Montrose District. The land use types for this crime hotspot were dominated by single-family housing (47%), multi-family housing (29%), and undeveloped land (20%). Single-family and multi-family housing represented the largest land use area in acres for robbery Gi Bin +3 crime hotspots. This does not necessary mean that single-family and multi-family housing are the cause of robbery hotspots.

The 2020 Theft Optimized Land use occurred in the downtown, midtown, Montrose, and Kirby districts. This large crime hotspot extended into the bar district along Washington Avenue. The dominant land use types for this crime hotspot were single-family housing (55%), multi-

family housing (17%), commercial (5 %), and industrial (3%). A second crime hotspot occurred in the western portion of the upper Kirby District dominated by single-family housing (67%) and multi-family housing (25%). Along I-610 in the western section of the study area, a small theft hotspot popped up in 2020 in a neighborhood dominated by multi-family housing (54%), and single-family housing (38%). Overall, single-family housing once again represented the largest land use type in area (acres) for most of the Gi Bin +3 areas of theft.

5.1.5 Crime and Natural Disasters

Hurricane Harvey occurred on 08/25/17. Crime was analyzed from 07/17 to 10/17 to include the month before Hurricane Harvey and two months following this major hurricane. Assault, burglary, and theft all trended downward from 07/17 to 10/17 and robbery trended upward during this same time period.

Tropical Storm Imelda occurred on 09/17/19. The general trend for the crime rates one month before and one month after this event was a general decrease in numbers of crimes from 08/19 to 10/19.

Tropical Storm Beta occurred on 09/21/20. The general trend for crime before and after this event is a general increase in assault, robbery and theft in October compared to August 2020. Theft increased significantly and burglary was the only crime type to decline from 08/20 to 10/20.

In summary, crime before and after Tropical Storm Beta increased for all types, but for Burglary, crime decreased for all types before and after Tropical Storm Imelda, and crime before and after Hurricane Harvey trended downward for all, but robbery. Hurricane Harvey was the only natural disaster included in this study that occurred before 2018. The two tropical storms occurred in 2019 and 2020 during the same temporal period of this crime study.

5.2 Successes, Challenges, and Failures

As with any large project, one concludes reflecting on aspects of the project they feel went well and areas that did not go as expected. Understanding these successes, challenges, and failures can shape future research by the researcher or others.

One success of this study was the geocoding of the study boundary crime addresses. The ArcGIS World Geocoding Service proved to be time efficient and accurate. For example, there were 13,944 crime occurrences between the dates of July-August 2020 for the study boundary edge test. The ArcGIS World Geocoding Service was used to geocode these crime addresses and 97.22% were matched and 0% were left unmatched. The remainder (2.8%) were returned with two or more of the same addresses or block locations.

Of course, there were also challenges faced in this study. The first was the 100,000+ crime addresses that needed geocoding. This was simply because of the huge number of records being processed. The second challenge was merging the 1st and 2nd geocoding attempts with the CDX WinZip geocoder for Excel into one master file for each year due to the large volume of data. The third challenge was matching the columns (attributes) of the 3rd geocoding attempts in Geocoding by Smart Monkey with the other geocoding solutions, CDX WinZip and ArcGIS World Geocoding Service. When matching these attributes, address, city, state and zip needed to be merged into one attribute column. This was accomplished by creating a concatenated formula.

One way the project failed to meet objectives was the inability at first to geocode the 2018 theft crime occurrences. Given more than 18,000 thefts, there were simply too many crime sources given the data processing capabilities using the default settings. The solution was to remove two attributes (theft from building and theft of motor vehicle parts or accessories) from

the 2018 Theft records. This reduced the number of 2018 thefts to a more manageable 12,597 occurrences.

The biggest challenge of the data management part of project was merging addresses for each geocoding attempt. As previously discussed, the (successful) initial attempt was saved in Excel, the unsuccessful addresses (those that were not located) were rerun using the ambiguous check box tool, and the final batch was merged using Geocoding by Smart Monkey. While it was challenging to remove the unsuccessful attempts, they were later added to the spreadsheets once the latitude and longitude coordinates were located using Geocoding by Smart Monkey. Again, the main challenge was the amount of data (100,000+ crime addresses). The process would have been more efficient if the Esri Geocoding Service had been used for all of the 2018-2020 crime addresses. CDX WinZip geocoding and Geocoding by Smart Monkey were utilized as a test of effectiveness.

The tools used in this project were adopted optimistically, with the knowledge that their effectiveness would be better understood after they were put to the test. The CDX WinZip geocoding tool was used with the 2018 and 2019 data to test the effectiveness of a geocoding technique other than Esri's World Geocoding Service. It proved to be effective, but not as efficient as Esri's World Geocoding Service. Esri's World Geocoding Service worked better given the sheer volume of data being geocoded, as evidenced by the efficient geocoding of the 2020 Edge Effect crimes. CDX WinZip is a powerful tool for geocoding when each batch of addresses contains a few thousand addresses.

The kernel density tool proved effective, despite the large amount of data. It was still able to distinguish points from one another, despite their close proximity, and create density hotspot maps. The Kernel Density Tool was successful using the default settings in ArcGIS Pro. This

customized the distance band and raster grid cell size for each dataset of crime points based on the number of crime points. The default settings accounted for the number of crime points and the size of the area to create customized settings for each dataset. Having learned a great deal from this project, future analysis of this data could involve the manipulation of the defaults to experiment with the implications of manipulating the data with carefully chosen rather than default inputs.

The exception to the success of the kernel density analysis was the 2018 Theft data, where there were too many occurrences (18,962) in close proximity, more than any other crime type or year. While there were attempts to create distance bands and parameter settings for the 2018 theft hotspots at 18,962 crime occurrences, it did not prove successful. The solution was to remove two attributes from the 2018 theft data and reduce the number of crimes to 12,597.

5.3 Implications for Law Enforcement

The intended audience of this project was law enforcement personnel and authorities in the Houston area. As previously discussed, knowing past and current crime hot spots can help law enforcement with planning and preparing for police patrols. This study strongly suggests that police should focus their efforts more on the downtown and midtown districts, as the primary category 5 and category 4 hotspots occurred at the intersection of the downtown, midtown and Montrose districts. These types of areas could be allocated more law enforcement funding and personnel, such as adding a police station and/or additional police resources.

In addition to law enforcement focusing on the areas with the highest crime, being able to identify areas of moderate to high crime (category 3 and 4 hotspots) can allow measures to prevent these areas from getting worse. For example, Kirby Drive and I-69 saw medium sized category 4 and 3 clusters. Southeast of I-69 and 288, another category 4 and 3 cluster appeared at

the intersection of Sampson and Elgin. These areas are critical places in which law enforcement could and should take preventive measures.

Law enforcement organizations could learn from these findings and prioritize their resources accordingly. By changing city policy and providing more police resources in critical areas, the growth of crime in Houston could be curtailed. The category 4 and category 5 hotspots could be changed into category 3 hotspots. More policing could also prevent category 2 and 3 hotspots from turning into category 4 and 5 hotspots. And were this study replicated in the future, the impacts of these changes may be temporally and spatially evident.

5.4 Future Research

This study looked at changes in crime and crime types over time in the inner 610 loop of Houston, TX. It also looked at related variables that may help better understand crime distributions. However, in the future, a number of changes could be made to increase efficiency with respect to data management, visualizations, and to explore related variables in more depth.

A new approach and method could involve more police input and participation to make the data more usable to law enforcement on-the-ground. In particular, the needs and opinions of law enforcement should be taken into account, and/or their personal experiences could be incorporated. For one, law enforcement agencies are likely familiar with which types of crimes are committed in which types of land use zones. This type of knowledge could be mapped using participatory GIS techniques and be used to ground-truth the data generated through the spatial analysis methods. Another way in which use the input of law enforcement officers would be with respect to the resources needed to enforce and address different types of crime. While some types may require more human-power and be more risky, others are less so. The ability of law enforcement agencies to address certain types of crime more efficiently than others could lead to

further suppression of high and medium crime hotspots for all crime types. These types of considerations could inform future studies to focus on certain crime types, areas, and time periods while eliminating the areas of the study that law enforcement believes to be less helpful.

With respect to data management, most suggestions for future research are meant to make workflows more efficient. Should a researcher seek to conduct a similar study, they must take three criteria into account: population, time period, and crime rates, also known as counts. The higher each of these are, the more bandwidth and more time the study will take. Based on the scope of their project, a future researcher should carefully consider the priorities of the study and allocate resources accordingly.

To start, Esri's World Geocoding Service could be used for all of the geocoding tasks. A master spreadsheet would not have to be created to match all attributes and columns from different geocoding services such as CDX WinZip and Geocoder by Smart Monkey. This would reduce the number of geocoding services utilized from three to just one. Another improvement would be a faster and more efficient method of geocoding the crime addresses. A workflow could also be created in ArcGIS Pro and/or Model Builder to enhance and accelerate the geocoding process.

With respect to visualization techniques, crime trends could be better explained using a Space Time Cube. Space Time Cubes allow the viewer to understand crime trends over periods of time using 3D visualization. This can help determine new hotspots, consecutive hotspots, intensifying hotspots, persistent hotspots, sporadic hotspots and historic hotspots. Techniques from behavioral geography and cognition could be used to understand what types of visualizations are clearer to a viewer.

Future studies could also look at the role of disruptions on crime. Disruptions could include hurricanes and other natural disasters, or epidemiological emergencies like the COVID pandemic. These types of disruptions can impact crime rates and types, including migration, lack of basic resources and general scarcity. Looking at the differences in crime rates either within or between cities before and after a disruption may enable disaster agencies to be better prepared. Understanding the demographics of cities that are more or less resilient to crime after disasters could help general readiness.

More broadly, the techniques used in this study could be applied to other cities that experience similar impacts due to rising crime rates. The GIS techniques used in this study are not exclusive to Houston, although each city is likely to have its own unique crime data attributes and challenges. A study based on the needs of another region could use similar techniques to achieve different objectives. For example, a study of an area with traffic challenges could provide optimized routes from police stations to crime hotspot locations. Perhaps predictive models could be created to anticipate the development of hotspot types and locations in the future.

This project sought to use spatial data to create up-to-date analysis and visualization of crime types and frequency in Houston, Texas. The process included the careful geocoding of a huge volume of crime data, and explains the types of accommodations that were made to achieve the project's goal. Land use types and bus stops were considered as possible related or explanatory variables. The relationships between crime rates before and after natural disasters were examined. Ultimately, the project provides analysis and visualizations that could be of use to law enforcement agencies and personnel. These techniques could be replicated or built upon in different cities to achieve similar or different objectives. This research seeks to improve the

efforts of law enforcement in reducing crime, thus improving the quality of life for urban residents.

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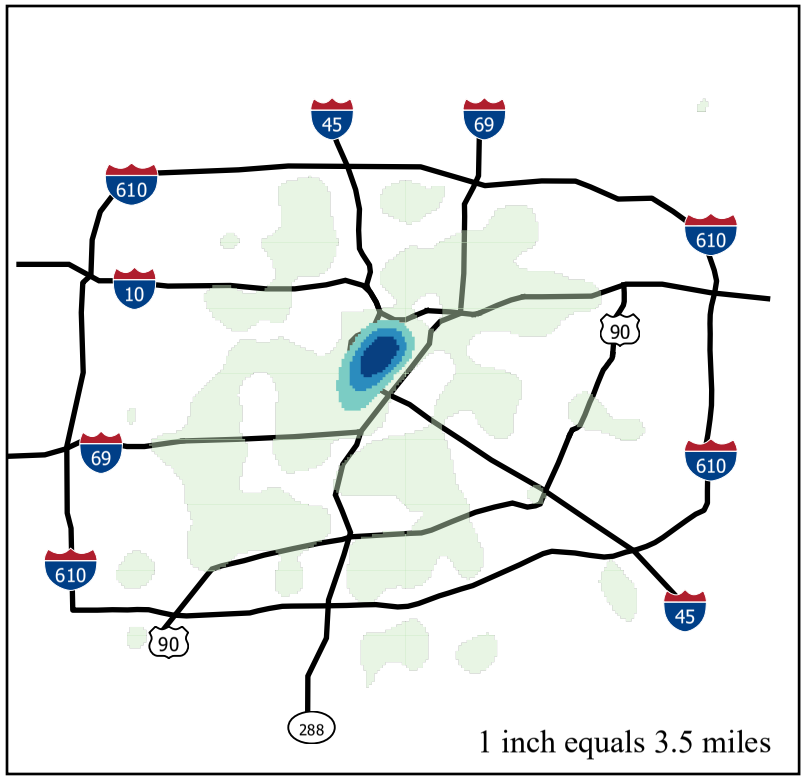
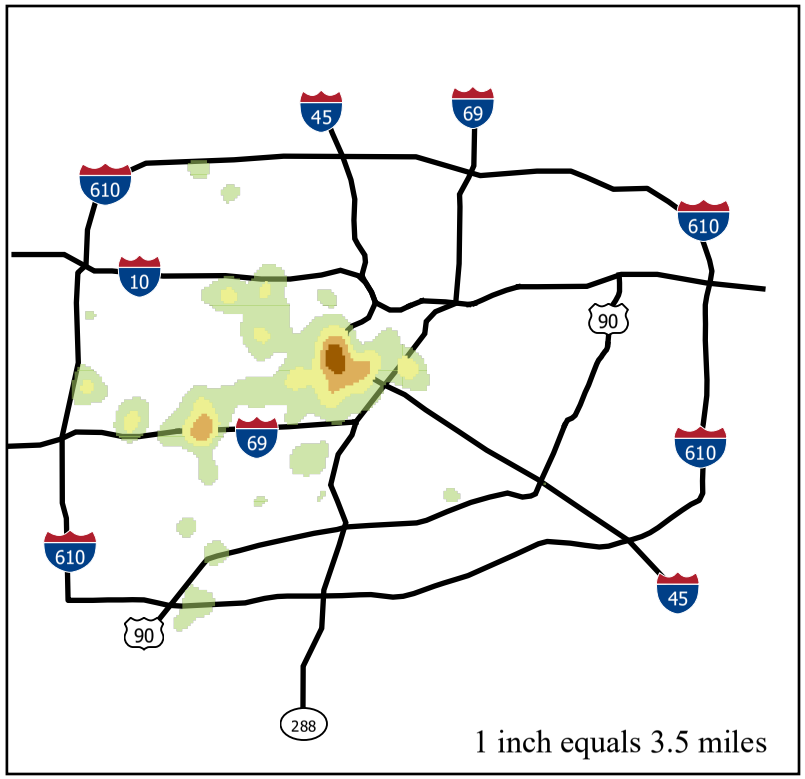
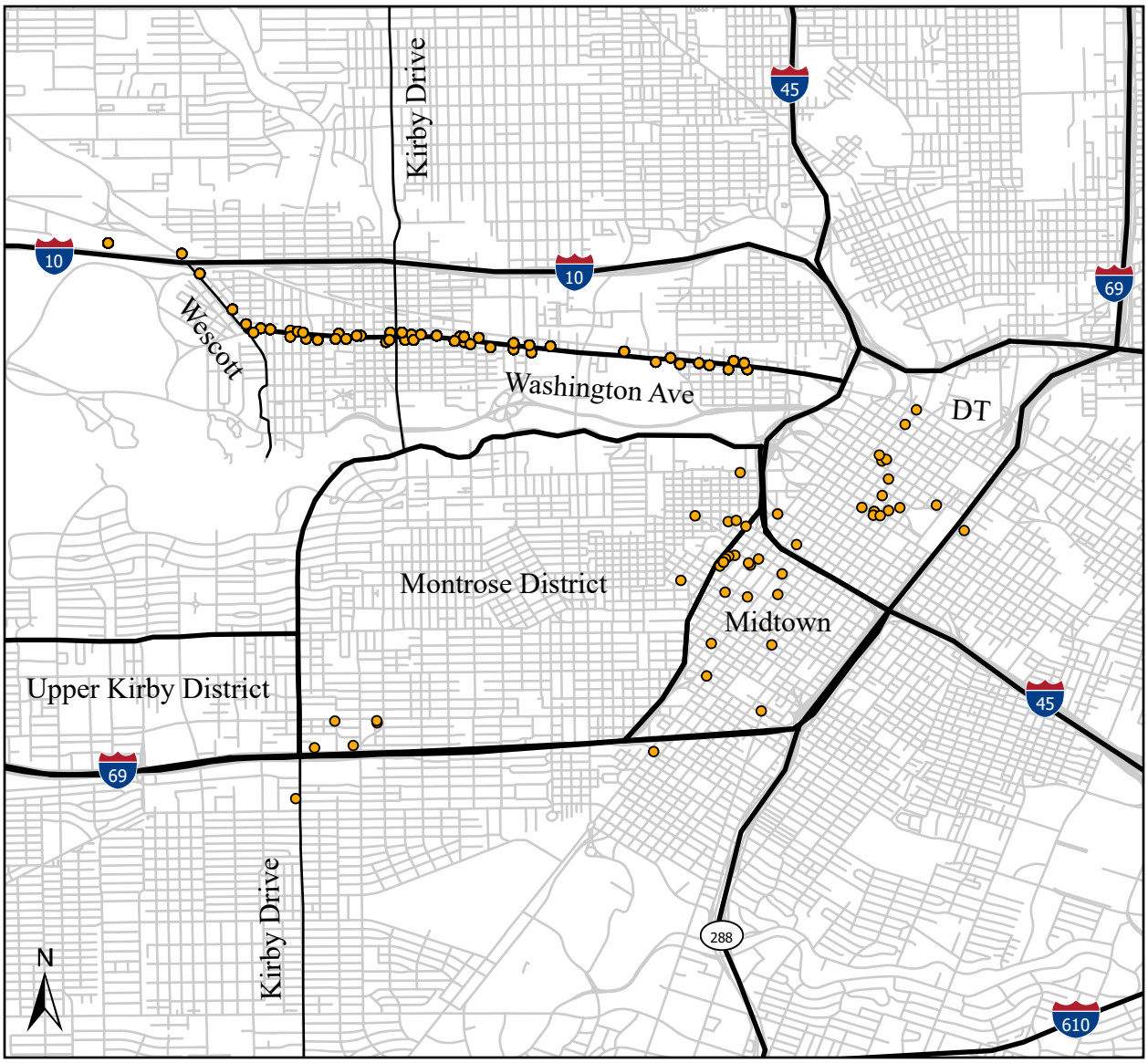


(a) Bus Stop Density



(b) 2020 Theft Hot Spots

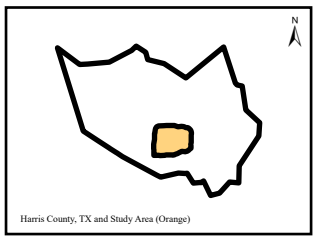
Appendix A. Bus Stop Density and 2020 Theft Hotspots



1 inch equals 1 mile

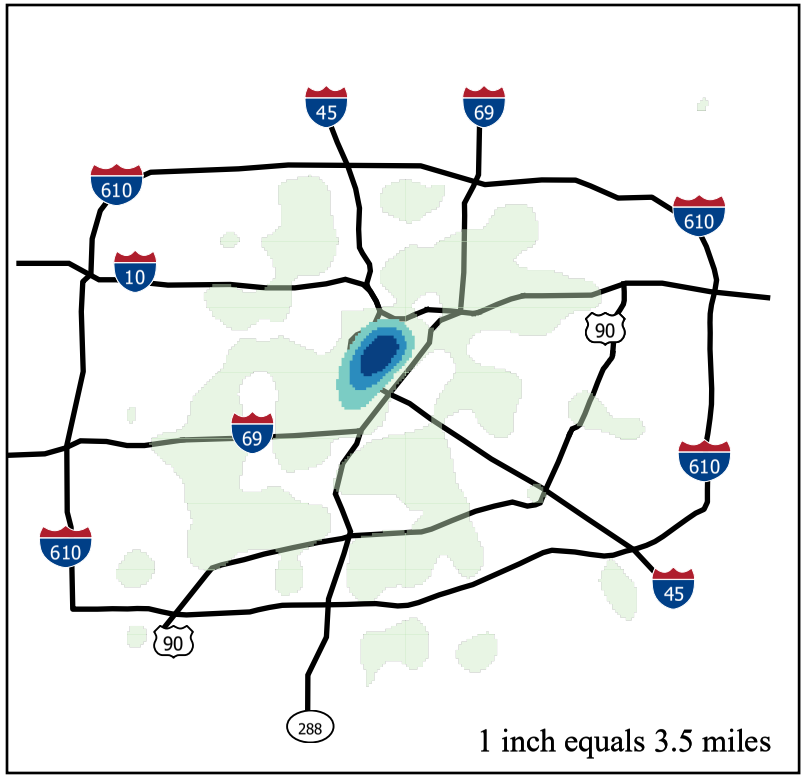
Top 50 Bars

Houston Streets

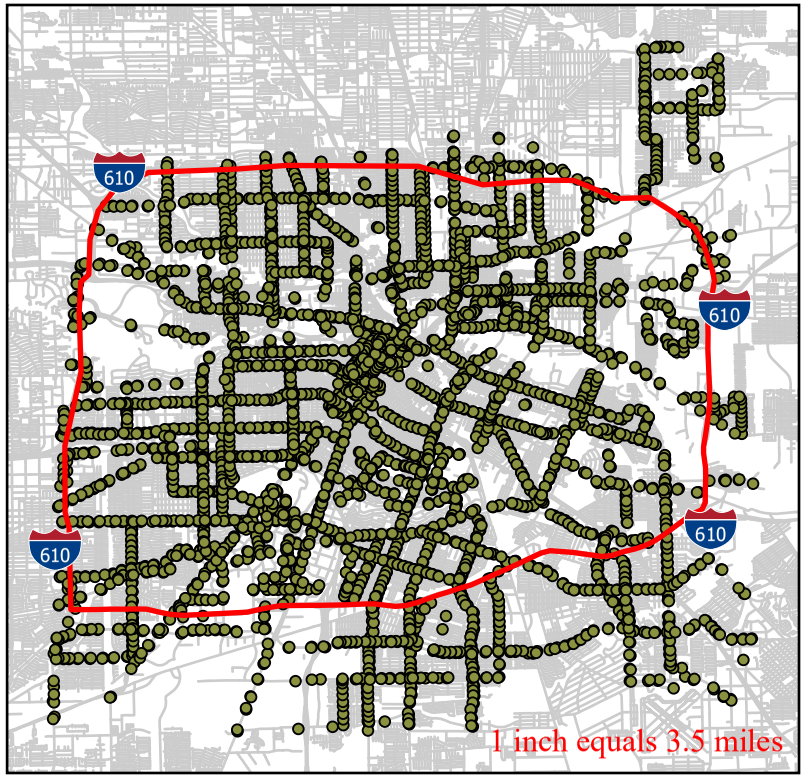


0 15 30 60 Miles

Appendix B. The bar locations within the Study Districts.

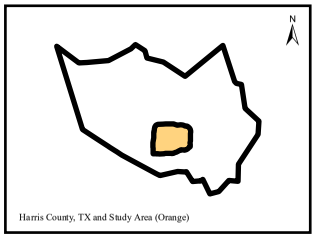


(a) Bus Stop Density



(b) Metro Bus Stops

Bus Stop Density
VALUE
Low
Medium
High
Very High



COH METRO BUS STOPS
Houston Streets
Interstate 610

Appendix C. Metro Bus Stop Density