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Crime Rate Prediction and Visualization Using Data Science Techniques

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Abstract

Crime remains one of the most pressing global social challenges, with rising crime rates negatively impacting public safety, economic stability, and national development. Effective crime prevention requires proactive strategies supported by advanced technological tools. This research focuses on crime prediction using machine learning and data science techniques to help law enforcement agencies make informed, real-time decisions. The study involves the preprocessing and analysis of crime datasets from various regions, including the Chicago and Denver crime datasets, using classification algorithms such as Random Forest.

Through pattern detection, classification, and visualization, the system identifies high-risk areas (hotspots), frequent crime types, and temporal trends. Furthermore, this work compares crime data across multiple U.S. cities and examines socio-economic factors like population, poverty, and unemployment that influence criminal behavior.

A systematic literature review of over 100 studies from 2018 to 2024 supports the use of supervised learning as the most widely adopted approach. Despite progress, challenges remain in model accuracy and data integration. Future improvements include leveraging diverse data sources such as social media, economic indicators, and urban mobility patterns, and employing hybrid machine learning models to enhance predictive power. This study contributes to the development of intelligent, data-driven crime prevention systems for safer communities.

Keywords: Crime Analysis; Crime Prediction; Machine Learning; Random Forest; Decision Trees; Pattern Detection; Data Visualization; Crime Mapping.

1. Introduction

The rapid rise in crime rates across the globe, from local communities to large metropolitan cities, has become an urgent concern for law enforcement agencies, policymakers, and researchers alike. Criminal activities—ranging from theft, assault, kidnapping, and homicide to more organized offenses such as trafficking and cybercrime—disrupt societal order, hinder economic development, and threaten public safety.

This multifaceted issue has compelled governments and research institutions to adopt more data-driven and technologically advanced methods for crime prevention and prediction. Traditionally, crime analysis relied on manual statistical methods and reactive strategies. However, the digital transformation of law enforcement and the proliferation of large-scale crime data have enabled the development of sophisticated analytical tools.

In recent years, machine learning (ML) and data visualization techniques have emerged as transformative approaches to understanding crime patterns, predicting future incidents, and identifying crime hotspots. These technologies allow for the processing of diverse data sources, including police reports, socioeconomic indicators, spatial data, and even social media activity.

In Nigeria, for example, increasing violence across its geopolitical zones—driven by banditry, kidnapping, and other forms of organized crime—has triggered urgent calls for predictive solutions.

Due to the lack of accessible, comprehensive national crime datasets, researchers have turned to international datasets like the Denver Crime Dataset to test and validate ML models. Similarly, studies across U.S. cities such as Chicago, Dallas, Baltimore, and Denton have demonstrated how demographic and economic factors such as poverty and unemployment correlate with crime trends. Systematic literature reviews affirm that supervised machine learning algorithms—such as Random Forest, Decision Trees, and Support Vector Machines—have been the most widely used and effective in crime prediction applications.

These models not only assist law enforcement in forecasting potential threats but also optimize resource allocation and enhance situational awareness. Furthermore, advancements in geospatial analysis and visualization tools offer real-time insights that empower communities and authorities to engage in proactive policing and urban safety planning. Despite their potential, these technologies are not without challenges.

Concerns over data privacy, algorithmic bias, interpretability of models, and the ethical implications of predictive policing continue to prompt caution. Nevertheless, the integration of ML, immersive analytics, and geospatial tools signifies a paradigm shift in criminal justice, from reactive response to preventive strategy. This research aims to consolidate insights from recent work in the field and apply advanced ML techniques to crime data analysis and prediction.

The goal is to uncover patterns, predict potential criminal incidents, and support the development of smarter, safer communities through informed decision-making.

2. Related Work

Big cities are experiencing large crime and there is a need for using data mining and deep learning techniques for crime analysis [1]. New methods and analysis needs to be explored to analyze heterogeneous and multi-sourced data [2]. Big Data analytics is widely used approach to analyze data and extract information for various applications. It can be deployed to aid businesses with more effective operations and high profits. Raghunath et.al [3] have described the potential of big data analytics in healthcare and have summarized current challenges. Zhang et al.

[4] proposed a big data analytics architecture for cleaner manufacturing and maintenance processes of complex products by including service driven patterns to assist in the decision making. Big Data analytics has also been explored for electronic markets [5] and tourism domain [6]. Big Data analytics can easily aid in identifying crime patterns that occur in a particular area over a period of time. The analysis of machine learning and deep learning techniques on crime enable the analysis and extraction of associated patterns and trends in crime prevention. Lately, immersive analytics is gaining lot of popularity in visualization of data by incorporating human ability to analyze and make use of heterogeneous data.

Reehl & Sharma [7] have demonstrated a data visualization tool to visualize Baltimore crime data in immersive environment and non-immersive environment. They have incorporated 3D interaction techniques over geographical information to enhance situational awareness of crime data. Their data visualization tool helps the user more in analyzing data with human-in loop interaction.

Their data visualization tool was developed using the Unity gaming engine and provides an understanding of crime data for different counties for decision making. Their data visualization tool incorporates the Baltimore city map and provides the functionality to toggle on/off the different variables related to the crime data. Sharma et al. [8-11] have used Unity 3D and Multitude GIS to visualize COVID-19 data and crime data in Baltimore.

There work is focuses on finding parameters that influenced the vulnerability of African Americans to COVID-19. They have found correlations between COVID-19 and crime in Baltimore city. Sharma et al. [12-17] have also presented data visualization tool for building evacuation and navigation in multilevel spaces by generating augmented reality (AR) instructional visualizations.

3. Analysis of Crime

A nation's development is hampered by crime, which infects and disturbs society as a hazardous substance. Its effects are felt in many areas, impeding stability and advancement.

First, crime weakens social cohesiveness and trust in society, preventing the involvement and cooperation required for growth on a collective level. Second, it is economically burdensome since it diverts funds away from important industries like healthcare and education, discourages investment, and slows down corporate expansion.

The development of human capital is also hampered by crime, which also jeopardizes public safety and the availability of high-quality healthcare and education. It undermines the rule of law and degrades institutions and general government. Nations may establish a climate that is favorable to growth, social well-being, and sustainable development by combating crime through comprehensive methods.

Crime is any illegal, punishable act that is committed against any individual or group to cause them harm either directly or indirectly. One of the principal crimes that are occurring at a fast pace from rural to urban regions include robberies, looting, sexual harassment, rape, abduction, and homicides. Crime is a terrible deed for all of humanity and a roadblock to the progress of society. The legal definition of crime exposes us to a huge array of difficulties and complexity since what we define as a crime is a social construction. It is debatable and dynamically contingent.

In other words, crime varies depending on the period and place. Each person and society have a different sense of reality, which is socially constructed. Based on shared conventions, values, and beliefs, each community creates its conception of reality. As cultures change and adapt to new conditions, the reality is not static but rather is always changing. People's perceptions of and understanding of their surroundings can be greatly impacted by social, political, and technological changes.

3.1. Comparison of crime statistics for the cities of Denton, Baltimore, Chicago, and Dallas

Data preprocessing has been conducted based on the information gathered from city websites to obtain the necessary properties, including Year, Crime Type, and City. To comprehend the increase in crime based on time series, a comparison is made between 4 different cities as well as the analysis of the data is done through Tableau. Fig. 2 provides a comprehensive overview of crime rates in various cities from 2020 to 2022.

In 2020, Chicago recorded the highest crime rate at 212,141 incidents, while Denton had the lowest crime rate at only 10,532 incidents. In 2021, Chicago's crime rate decreased slightly to 208,652 incidents, while Denton, Baltimore, and Dallas saw increases in crime compared to 2020. Both Chicago and Dallas report the most crime incidents in 2022, with 238,567 and 138,875, respectively, surpassing the figures for 2020 and 2021. Crime in Denton and Baltimore also slightly increased from previous years. In the second quarter of 2022, Chicago's crime rate continues to rise significantly, while Dallas, Denton, and Baltimore have crime rates of 45,744, 5,269, and 18,696, respectively.

These findings shed light on the changing crime landscape of these cities over the years. Chicago's crime rate fluctuated, peaked in 2022, and continues to increase. Dallas showed an overall upward trend, while Denton and Baltimore showed slight increases when compared with the rest of the two cities i.e., Dallas and Chicago. These figures underscore the importance of monitoring and addressing crime patterns so that policymakers and law enforcement agencies can implement targeted strategies to prevent crime and improve community safety.

It is worth noting that these statistics provide an overview of the crime rate in specific cities in the specified years.

Further analysis, including examination of underlying factors and contextual information.

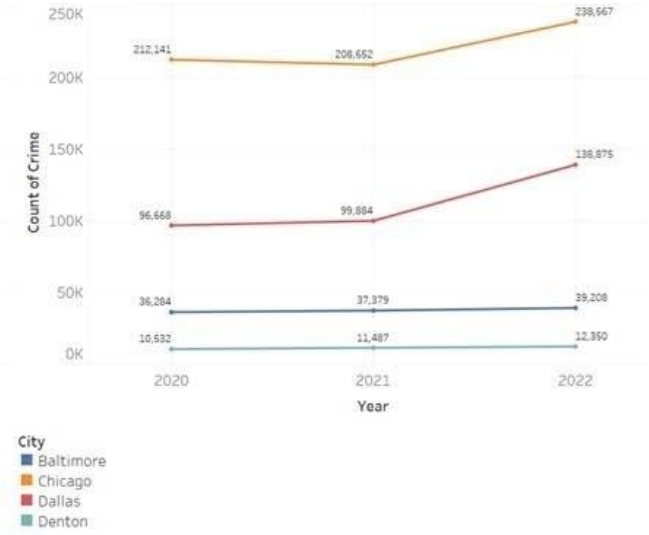

Figure 1. Shows the plot of the count of crime made using Tableau. The color shows each city. The view is filtered by year, which ranges from 2020 to 2022.

3.2. Crime Types

Crime can be divided into three main types: violent crimes, property crimes, and other crimes. Violent crime includes crimes involving direct or threatened bodily harm to individuals, such as assault, robbery, rape, and murder. Property crime focuses on crimes involving theft, destruction, or damage to property, including theft, burglary, car theft, and arson. Finally, other crimes include several different crimes such as kidnapping, drug crimes, vandalism, identity theft, and animal cruelty. These categories serve as a framework for understanding different types of crime. Violent crimes pose a direct threat to personal safety and well-being, while property crimes target property and cause financial harm and emotional distress to victims. Other crimes include a wide range of crimes that do not fit strictly into the classification of violent or property crime, but which still have a significant impact on individuals and communities.

By classifying crimes into these categories, law enforcement agencies, policymakers, and researchers can better analyze crime data, identify patterns, and develop targeted strategies for crime prevention and resource allocation. However, it is important to note that classification may vary slightly depending on jurisdiction and regional definitions. However, this framework provides a useful way of categorizing criminal activity and understanding its multifaceted nature. Based on [18] the statistics of crime rate are shown in the table 1.

Table 1. Statistics of Crime rate

	Chicago	Baltimore	Dallas	Denton
Violent crime rate	4.728	11.93	5.473	1.723
Property Crime rate	24.83	37.28	25.98	14.20
Other Crime rates	11.53	13.36	14.28	13.02

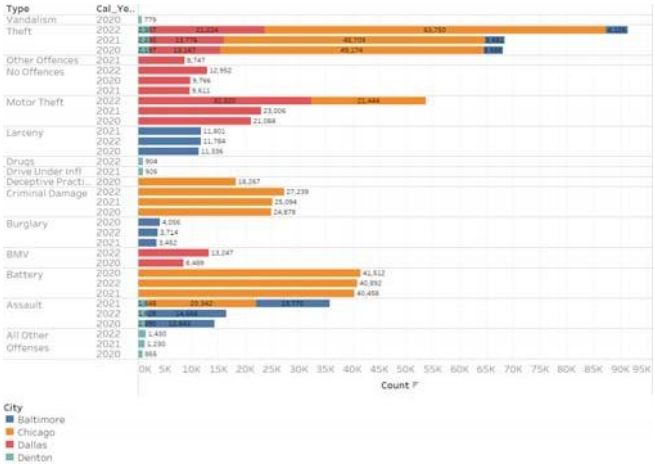

Figure 2. Crime types in Chicago, Baltimore, Dallas, and Denton

Fig. 2 shows that in Chicago, theft is the highest crime being recorded in all three different years it seems like there is a high spike from 2021 to 2022 with a rate of change of 30.879 and the second highest crime recorded in battery with an average of 40000 per year. Additionally, assault criminal damage motor theft falls in a median range of crimes being committed with a count of 20000 approximately, and motor theft has drastically increased from 2021 to 2022, by twice the previous year. Burglary, criminal trespassing, deceptive practice, drugs, and all other offenses fall between the 5000 to 20000 range and especially drug rate has decreased by 58.75 when compared with 2020 and 2022. Arson, concealed carry license violation, fraud, harassment, homicide, human trafficking, intimidation, liquor law violation, obscenity, and public peace violation are recorded as low-level crimes.

In Baltimore, assault is the highest crime recorded in all three years (2020,2021,2022) with a rate of change is 6.50 from 2021 to 2022 and the second highest recorded in larceny with approximately 12000 per year also theft, burglary, and motor theft fall under the median range of crimes between 3000 to 5000, but theft has increased with a rate of 12.08 from 2021 to 2022 and low-level crimes such as arson, homicide, rape, and sex trafficking, shooting recorded less than 1000 each year, but shooting has reduced in 2022 compared to previous years. With a rate of change of 54.08 from 2020 to 2022, Dallas has the greatest rate of automotive theft. Theft, which seems to be the biggest number of criminal cases being reported with substantial variance, is the second highest recorded with a rate of change of 54.066 from 2021 to 2022. With a value ranging from 5000 to 15000, the following offenses fall within the median range: assault, burglary, criminal trespassing, organized crime, and others. Criminal trespassing grew from 2021 to 2022 at a rate of change of 57.11, whereas it decreased from 2020 to 2021 at a rate of 16.14. The rate of change for burglaries declined from 20.03 from 2020 to 2021 to 49.95 from 2021 to 2022. The assault has grown with a change rate of 24.15 from 2021 to 2022. Low-level

crimes like arson, credit card fraud, drunk driving, drug use while driving, harassment, murder, use of a prohibited weapon, property crimes, public intoxication, careless damage, and traffic violations fall into the 1 to 3000 range, and drug use has seen a slight increase with a rate of change of 38.08.

In Denton, theft is the highest recorded crime with a rate of change of 5.69 from 2021 to 2022. Assault is the second-highest crime recorded with a rate of change of 10.92 from 2021 to 2022. Motor theft, larceny, intimidation, fraud, drugs, and driving under the influence fall under the median range of 600 to 900 whereas motor theft has a spike in 2022 when compared with 2020 with the rate of change of 29.44. Driving under the influence has decreased from 2021 to 2022 with a rate of change of 25.64. Low-level crimes such as animal cruelty, burglary, disorderly conduct, kidnapping, liquor law violation, murder, nonviolent family of property crime, rape, sex trafficking, swindle with a range of less than 500. Disorderly conduct has increased from 2020 to 2022 with a rate of change of 46.09. Theft is the most common crime type recorded in the four cities. Assault is also the highest crime type in cities like Baltimore and Denton.

3.3. Crime based on demographics

The safest places to live are determined based on the amount of crime committed or recorded by different sources like the City Police Department and FBI. According to the most recent information accessible from several municipal websites, Denton data has a hidden address. Geo-coding has been used on the API to identify their latitude and longitude and their Zip codes. Whereas Dallas data have all the attributes like latitude, longitude, and zip code for geo-mapping analysis. Furthermore, Chicago and Baltimore data just have latitude and longitude, and reverse geo-coding has been applied to the API to retrieve zip codes. Fig. 4 shows the flow for geo-coding and reverse geo-coding.

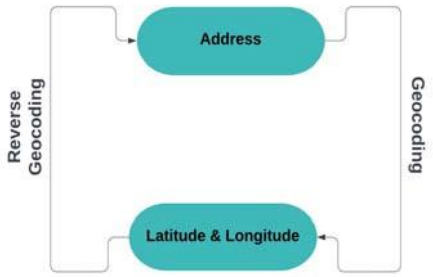

Figure 3. Flow representation of Geocoding and Reverse Geocoding

Geocoding is the conversion of a text address or location description into geographic coordinates (latitude and longitude). This involves translating human-readable location data such as addresses, landmarks, or place names into precise geographic coordinates that map systems and geographic information systems (GIS) can understand. Geocoding is a key component of map applications that enables visualization and analysis of data in a spatial context. It can be used to map and analyze different types of information from addresses and points of interest to crime and population data.

Reverse geocoding is the conversion of geographic coordinates (latitude and longitude) into a human-readable address or location description. It involves converting numerical coordinates into meaningful spatial data that humans can understand. Reverse geocoding is often used in applications that involve displaying a user's current location or indicating locations on a map. By providing a set of coordinates, reverse geocoding searches for related addresses, landmarks, or place names, allowing users to identify their location or explore the context of a specific point on a map. Both geocoding and reverse geocoding are important techniques for spatial analysis, mapping, and location-based services. Geocoding allows mapping data-specific locations, while reverse geocoding allows converting coordinates back into meaningful location data. These processes are very important for many applications, including navigation systems, location-based services, logistics, real estate, and urban planning.

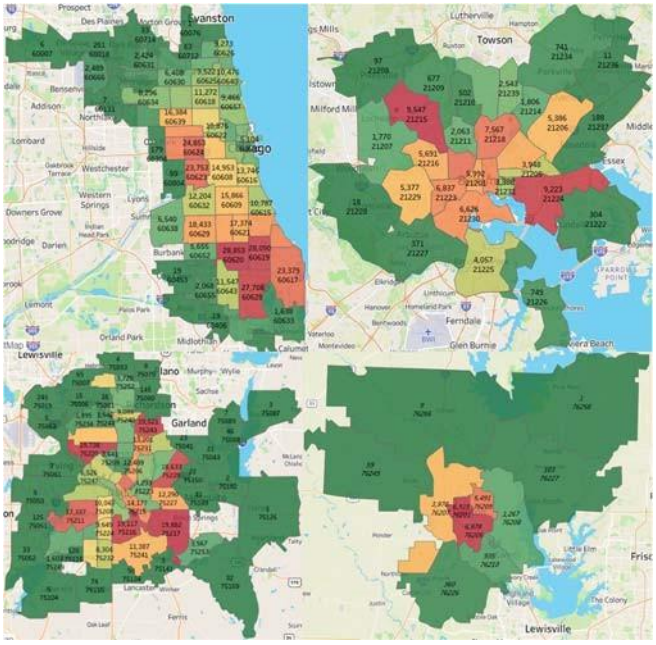

Figure 4. Flow Count of Crimes based on Zip code in Chicago, Baltimore, Dallas, and Denton from 2020 to 2022.

Fig. 4 shows an overview of the total number of crimes committed in Chicago between 2020 and 2022. Among the zip codes, 60076 stands out as the safest place to live, with a crime rate of 1. In contrast, zip codes 60628, 60619, and 60620 are classified as high crime " red flag zones". Several zip codes, including 60007, 60131, 60714, 60712, 60453, and 60406, are considered the safest areas with fewer than 150 reported crimes. In Baltimore, the map visualizes all crimes committed between 2020 and 2022. The 21236-zip code is one of the safest places to live, with only 11 reported crimes. In contrast, 212214 is considered a “red flag zone" as per the computation of crimes based on the zip codes, the color coding is done using the highest intensity of crimes to the lowest with a change in color from Red to Green. Other zip codes with crime rates below 200 that indicate safer areas are 21228, 21208, and 21237. All crimes in Dallas from 2020 to 2022 are depicted on the map. With a crime rate of 1, the zip code 75126 stands out as the safest area to live. On the other side, "red flag zones" with high crime rates have been detected in zip codes including 75216, 75217, 75220, 75243, 75228, and 75228. The 76205 and 76201 zip codes are in a high crime "red flag zone," whereas the area overall is a safe place to live with a crime rate of 1. The 76266, 76249, and 76227 zip codes

in Denton are other safe locations with crime rates that are under 150. These findings highlight disparities in crime rates between the ZIP codes of Chicago, Baltimore, Dallas, and Denton. By identifying high-crime areas and comparing them to safer zones, this data can help residents, law enforcement agencies, and policymakers understand crime patterns, effectively allocate resources, and implement targeted strategies to improve community safety.

Population density per square mile refers to the number of people living in a particular area. In Baltimore, this density is 7235.8 people per square mile of her, which means there are about 7235.8 people per square mile in the city. Similarly, Chicago has a population density of 12059.8, significantly higher than Baltimore, suggesting more people per square mile. Dallas, on the other hand, has a population density of 3841.1, lower than both Baltimore and Chicago, indicating fewer people per square mile of her in the city. Finally, Denton has the lowest population density of 1451.6 among the four mentioned cities, suggesting fewer people live per square mile of her city compared to other cities. doing. This population density provides important insights into the living conditions and overall population distribution of these cities and can also be used as the basis for urban planning and development decisions.

4. Analysis of Crime Comparison with Factor

Analyzing crime against factor such as population provides valuable information about the complex relationship between social factors and criminal behavior. By looking at these variables together, we can better understand the contextual factors that can affect crime rates in different areas.

4.1. Population

The population is an important factor in analyzing crime rates. Larger populations often have higher crime rates simply because the number of potential criminals and victims has increased. However, to get a more accurate view of the prevalence of crime, it is important to look beyond the raw number and consider the crime rate per capita. It helps compare crime rates in different areas and different population sizes and provides a standardized metric for evaluation.

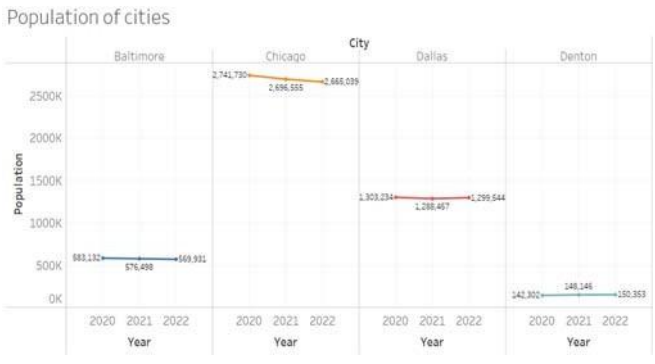

Figure 5. Count of Population in 4 Cities from 2020 to 2022

When analyzing crime about population, unemployment, and poverty rates, it is important to consider the interaction of these factors. For example, high population density combined with high unemployment and poverty can increase the likelihood of crime due to several factors such as social stress, limited resources, and reduced social mobility. By conducting a comprehensive analysis that integrates data on population, unemployment, poverty, and crime, policymakers, researchers, and law enforcement agencies can identify areas of greatest need for intervention and develop targeted strategies to address the social and economic drivers of crime. Such analysis can help inform resource allocation, community development initiatives, and crime prevention efforts aimed at breaking the cycle of crime and promoting safer, more prosperous communities.

Based on the [19], provides statistics for all the cities states, and counties with populations of 5000 and above, the population percentage change from April 1, 2020, to July 1, 2022. Baltimore's population decreased by 2.7%, Chicago's by 3%, Dallas' by 0.4%, and Denton's by 7.5%. However, there was an increase in population of 7.5% in Denton. Fig. 6 shows a population decline in Chicago between 2020 and 2022. Between 2020 and 2021, Dallas' population drops, then between 2021 and 2022, it slightly rises. Between 2020 and 2022, there is a population decline in Baltimore. Between 2020 and 2022, there is an increase in population in Denton. Chicago has the largest population, while Denton has the smallest.

4.2. Analysis of Crime with Population

Crime about the population provides important insight into the distribution and effects of crime in a given area. Understanding the relationship between crime and the population can help identify patterns, assess community safety, and inform targeted interventions.

Crime per capita provides a standardized metric that takes into account population size, allowing for more accurate comparisons between different areas. This approach allows us to understand the relative crime risk of a given population. However, estimating crime per capita allows for a fair comparison of crime rates in different areas with different population sizes. This helps identify areas where crime rates are higher relative to the population, potentially indicating higher risks and the need for targeted intervention. For example, population growth can lead to increased social interaction, changes in neighborhood dynamics, and changes in the distribution of resources, which can affect crime rates. However, it is important to understand that population alone does not determine crime rates.

5. Conclusions

Based on the statistics, the cities of Denton and Dallas have some correlation between population and crime rates. On the other hand, in Chicago and Baltimore, the population has decreased by 3%, but the crime rate has also increased between 2020 and 2022. Even though the crime rate is impacted by the population per square mile, it's important to keep in mind while viewing it in the crime map of the Chicago region that people who do not live in the area may visit throughout the day which inflates the rate of crime per person. The east side of the city, for instance, has more stores that sell goods. In neighborhoods with few residents, many crimes are perpetrated in commercial districts. It's not always dangerous for the locals of the Chicago region to be in the red zones on the crime rate map. When looking at the Dallas, population, and population density, the distribution of the population is at a medium rate but the people commuting via the red zone areas are high with the availability of retail stores, airports, parks, and schools.

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