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Exploratory Data Analysis And Crime Prediction In San Francisco

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Exploratory Data Analysis And Crime Prediction In San Francisco

A Project

Presented to

The Faculty of the Department of Computer Science

San Jose State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

Isha Pradhan

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The Designated Project Committee Approves the Project Titled
Exploratory Data Analysis And Crime Prediction In San Francisco

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ABSTRACT

Exploratory Data Analysis And Crime Prediction In San Francisco

by Isha Pradhan

Crime has been prevalent in our society for a very long time and it continues to be so even today. The San Francisco Police Department has continued to register numerous such crime cases daily and has released this data to the public as a part of the open data initiative. In this paper, Big Data analysis is used on this dataset and a tool that predicts crime in San Francisco is provided. The focus of the project is to perform an in-depth analysis of the major types of crimes that occurred in the city, observe the trend over the years, and determine how various attributes, such as seasons, contribute to specific crimes. Furthermore, the proposed model is described that builds on the results of the performed predictive analytics, by identifying the attributes that directly affect the prediction. More specifically, the model predicts the type of crime that will occur in each district of the city. After preprocessing the dataset, the problem reduced to a multi-class classification problem. Various classification techniques such as K-Nearest Neighbor, Multi-class Logistic Regression, Decision Tree, Random Forest and Naïve Bayes are used. Lastly, our results are experimentally evaluated and compared against previous work. The proposed model finds applications in resource allocation of law enforcement in a Smart City.

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CHAPTER 1

Introduction

The concept of a smart city has been derived as one of the means to improve the lives of the people living within the city by taking smart initiatives in a variety of domains like urban development, safety, energy and so on [1]. One of the factors that determine the quality of life in the city is the crime rate therein. Although there could be a lot of technological advancement in the city but the basic requirement of citizens' safety still remains [2].

Crime continues to be a threat to us and our society and demands serious consideration if we hope to reduce the onset or the repercussions caused by it. Hundreds of crimes are recorded daily by the data officers working alongside the law enforcement authorities throughout the United States. Many cities in the United States have signed the Open Data initiative, thereby making this crime data, among other types of data, accessible to the general public. The intention behind this initiative is increasing the citizens' participation in decision making by utilizing this data to uncover interesting and useful facts [3].

The city of San Francisco is one amongst the many to have joined this Open Data movement. The data scientists and engineers working alongside the San Francisco Police Department (SFPD) have recorded over 100,000 crime cases in the form on police complaints they have received [4]. With the help of this historical data, many patterns can be uncovered. This would help us predict the crimes that may happen in the future and thereby help the city police better safeguard the population of the city.

1.1 Motivation

The motivation behind taking up this topic for the research is that every aware citizen in today's modern world wants to live in a safe environment and neighborhood. However it is a known fact that crime in some form, exists in our society. Although we cannot control what goes on around us, we can definitely try to take a few steps to aid the government and police authorities in trying to control it. The SFPD has made the Police Complaints data from the year 2003 to 2018 (current year) available to the general public. Hence, taking inspiration from the facts stated above, we decided to process this data provided and analyze it to identify the trends in crime over the years as well as make an attempt to predict the crimes in the future.

1.2 Problem Formulation

The problem being tackled in this research can be best explained in two distinct parts:

1. Performing exploratory analysis of the data to mine patterns in crime:
 - The first step in determining the safety within different areas in the city is analyzing the spread and impact of the crime.
 - We utilize this provided crime dataset by the SFPD and perform exploratory analysis on it, to observe existing patterns in the crime throughout the city of San Francisco.
 - We study the crime spread in the city based on the geographical location of each crime, the possible areas of victimization on the streets, seasonal changes in the crime rate and the type, and the hourly variations in crime.
2. Building a prediction model to predict the type of crime that can take place in

the city,in the future:

- After observing the patterns of crime from the historical data as explained previous, the next thing is to predict the crimes that can occur in the future.
- Our goal is to build a prediction model that treats this problem as a multi-class classification problem, by classifying the unseen data into one of the crime categories (classes) thereby predicting the crime that can occur.
- This is expected to help the police plan their patrol and effectively contribute to building a smarter city.

For the first part, we will make use of various data analytics tools along with Spark for initial data preprocessing, to analyze the spread of the crime in the city. For the second part, in order to build a prediction model, we build upon the existing research work and improve their results by experimenting with different types of algorithms. Summarizing, we present the experimental results using graphs and statistics.

CHAPTER 2

Definitions and Techniques

In this chapter we will go over the details of some concepts and techniques which will be discussed and implemented throughout this research.

2.1 Predictive Analytics

Predictive analytics is the technique of analyzing the past or historical data in order to predict the future outcome. It is different from data mining. As explained in the Figure 1 [5], predictive analysis starts by capturing relationships between the different variables in the data. After that, hypothesis is developed based on these results. Following this, based on the outcome of the previous steps, a model is built in order to test this hypothesis



Figure 1: Data mining and predictive analytics.

There are numerous advantages of using Predictive Analytics in general. For example, an organization can study its internal data to identify trends in profit, so that they can adopt the necessary steps to possibly replicate that in the future. It is also a useful technique for professionals in the marketing industry as it can help decide which campaign successfully generated revenue and business. For the purpose of this research, Predictive Analytics is helpful for the following reasons:

- It will help us identify the progression in crime throughout the years

- It will help us closely observe the variables having highest correlation with the predictor or target variable
- Visualizing the data can even help map potential outliers, which can then be effectively handled during data preprocessing
- The analysis can bring up some interesting facts from the past which might prove to be useful to the SFPD while planning their patrol or strategies against crime

2.2 Classification Techniques

Classification techniques are used to segregate the data into one or more categories also known as class labels. The goal of classification is to create a certain set of rules that will either make a binary decision, or predict which of the multiple classes should the data be classified into. Classification can mainly be divided into two types:

1. Binary Classification

In Binary Classification, the goal is to classify the elements into one of the two categories specified, say, X and \tilde{X} (not X). To determine the efficiency of the Binary Classifier, we pass a set of inputs to the classifier and examine the output. There are 4 possible results - True Positive, True Negative, False Positive and False Negative [6]. Generally, 'Accuracy' is used to determine the efficiency of a binary classifier.

2. Multiclass Classification

Multiclass Classification involves classifying the data into more than two categories. The most common types of Multiclass Classifiers are [6]:

- **Pigeonhole Classifier:** In a pigeonhole classifier every item is classified into only one of the many categories. Hence, for a given item, there can be only one output category assigned to it.
- **Combination Classifier:** This type of classifier can place an item into more than one output categories. Hence, unlike a pigeonhole classifier, this type of classifier does not assign a unique category to each input.
- **Fuzzy Classifier:** These classifiers not only assign an input to more than one categories but also assign a degree to each category. This means that every input belongs to every category by a certain degree. Hence the output is an N-dimensional vector, where N is the number of categories.

For the purpose of this research, we will focus on the Pigeonhole Multiclass Classification algorithms.

Below we will look at some of the classification techniques that have been used in this research.

1. Naïve Bayes

Naïve Bayes classifiers are a set of supervised learning algorithms which are based on the Bayes' theorem. The Bayes' theorem can be stated as shown in Figure (1),

$$P(\mathbf{A}|\mathbf{B}) = P(\mathbf{A}) \frac{P(\mathbf{B}|\mathbf{A})}{P(\mathbf{B})} \quad (1)$$

Here,

$P(\mathbf{A}|\mathbf{B})$ is the conditional probability of A happening given that B is true

$P(B|A)$ is the conditional probability of B happening given that A is true and $P(A)$ and $P(B)$ are the individual probabilities of A and B happening independently

All the Naïve Bayes algorithms have the naïve assumption that there exists independence between all pairs of features. That is, each feature independently contributes to the probability of the target variable. Although these classifiers are fairly simple in nature, they tend to work very well in a large number of real world problems.

2. Decision Trees

Decision Tree classifiers use decision trees to make a prediction about the value of a target variable. The decision trees are basically functions that successively determine the class that the input needs to be assigned.

A decision tree contains a root node, interior nodes and terminal or leaf nodes [7]. The interior nodes are the splitting nodes, i.e. based on the condition specified in the function at these nodes, the tree is split into two or more branches.

Using decision trees for prediction has many advantages. In a decision tree classifier, an input is tested against only specific subsets of the data, determined by the splitting criteria or decision functions. This eliminates unnecessary computations [8]. Another advantage of Decision Trees is that we can use a feature selection algorithm in order to decide which features are worth considering for the decision tree classifier. The lesser the number of features, the better will be the efficiency of the algorithm [7].

To construct a decision tree, generally a top down approach is applied until some predefined stopping criterion is met. Figure 2 depicts an example of a decision

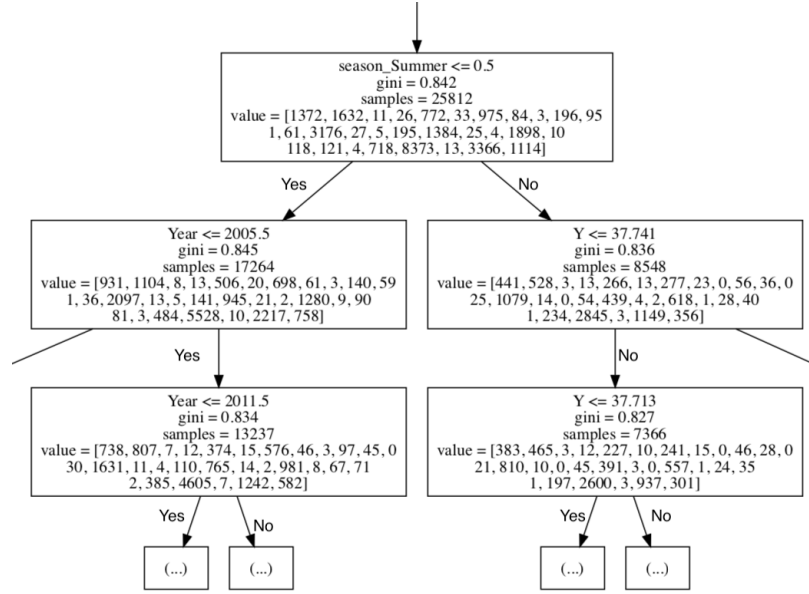


Figure 2: Decision Tree Example

tree which splits a node based on the best attributes of the Crime Classification dataset [3], which is what is used in this research.

3. K- Nearest Neighbor

According to the K-Nearest Neighbor (KNN) algorithm, data is classified into one of the many categories by taking a majority vote of its neighbors. The label is assigned depending on the most common of the categories among its neighbors. In other words, we identify the neighbors closest to the new point we wish to classify and based on these neighbors, we predict the label of this new point. The number of neighbors to consider can be a user-defined constant K as in the case of K-nearest neighbors or it can be based on the density of points in a certain radius specified [9].

The distance metric used can be Euclidean or Manhattan if the target variable is a continuous variable or Hamming distance if the target variable is a categorical variable

The Figure 3 illustrates a simple KNN classifier. Here, the green circle in question would be categorized as a red triangle if we consider $k=3$, i.e. if we consider its 3 nearest neighbors. If $k=5$, then it would be categorized as a blue square.

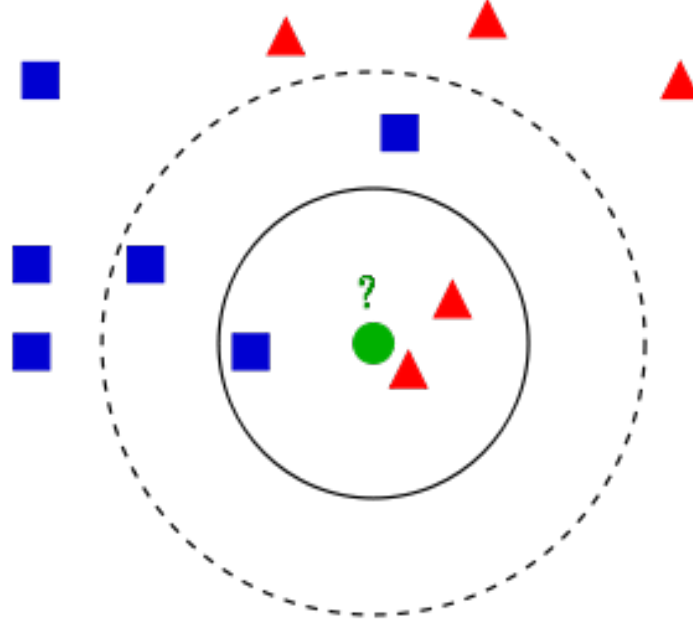


Figure 3: KNN Classifier Example

4. Multinomial Logistic Regression

Multinomial Logistic Regression is a technique used for classification of data in which the log odds of the output is modeled as a combination of the various predictor variables [10]. It is a more generalized version of Logistic Regression. There are two variants of Multinomial Logistic Regression based on the nature of the distinct categories in the dependent variable- nominal and ordinal [11]. It is specifically designed to handle multiple output categories.

Multinomial regression uses the Maximum Likelihood Estimation (MLE) method [10]. Logistic Regression is a discriminative classifier [12][Chapter 7]. This means that it tries to learn the model based on the observed data directly

and makes less assumptions about the underlying distribution.

5. Random Forest

A Random Forest Classifier generates multiple decision trees on different subsamples of the data while training, and then predicts the accuracy or loss score by taking a mean of these values. This helps to control over-fitting [9].

In the Random Forest algorithm, the split for each node is determined from a subset of predictor variables which are randomly chosen at the given node [13]. This is done using the Out-Of-Bag (OOB) approach specified by Breiman [14]. Here, an inbag dataset is formed using the training set. A few samples from this training set are set aside (also called the OOB data) for testing the random learners. The average of the samples misclassified is taken and is used for judging the performance of the learner [14].

2.3 Log Loss Scoring

In case of multiclass classification, the baseline (or worst-case) accuracy would be: $\frac{1}{N}$, where N is the number of distinct categories of the dependent variable. Thus, for an output variable with 30 different categories, the worst-case would be an accuracy of 3.33%. In such a case, accuracy might not necessarily be a good measure of the efficiency of the model. Hence we consider measuring the performance of the model using Log Loss scoring.

A Log Loss score is used when the model gives out a probability for the prediction of each class. In this scoring metric, false classifications are penalized. The lesser the log loss score, the better is the model. For a perfect classifier, the log loss score would be zero [15].

Mathematically, the Log Loss function is defined as follows:

$$-\frac{1}{N} \sum_{i=1}^N \sum_{j=1}^M y_{ij} \log p_{ij} \quad (2)$$

Here, N is the total number of samples, M denotes the number of distinct categories present in the output variable, y_{ij} takes the value of 0 or 1 indicating if the label j is the expected label for sample i and p_{ij} if the probability that label j will be assigned to the sample i [15].

The scikit-learn(sklearn) library (written in Python) provides a method for calculating the Log Loss score of a machine learning model, which is defined in the sklearn.metrics package [16]. In the most simplest form, the method provided by the sklearn library is given as: $\log_loss(y_{true}, y_{pred})$, where y_{true} is the expected value of the output variable and y_{pred} is the predicted value.

2.4 Parallel Processing using Apache Spark

Apache Spark is a big data tool which distributes the data over a cluster and achieves parallel processing. It has become popular in the recent few years [17]. Apache Spark has a master-slave architecture.

The *SparkContext* is the driver program which interacts with a *Cluster Manager* as shown in the Figure 4 [18]. The Cluster Manager is connected to the Executors present on each Worker node. It runs the computations and stores the application data. Every Spark job is divided into stages and each stage in turn has multiple tasks. It is the job of the Driver to convert the application data to tasks.

The fundamental feature of Spark is the Resilient Distributed Dataset (RDD). RDDs are basically a collection of elements which are distributed or partitioned across nodes

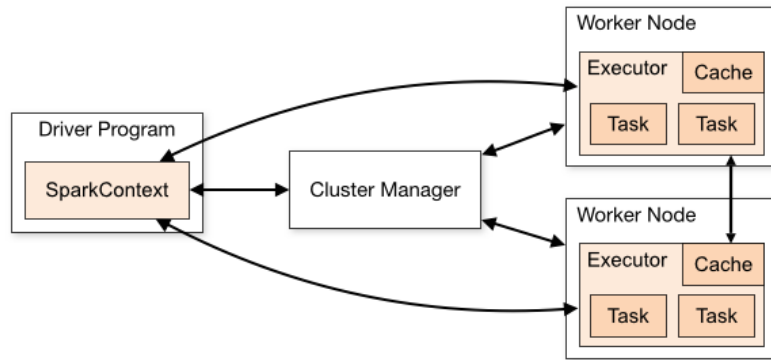


Figure 4: Spark Architecture

in your cluster. These can be run in parallel. One advantage of using RDDs is that they are fault tolerant and hence they automatically recover from failures. Users can request that the RDDs be stored in memory for faster processing [17].

CHAPTER 3

Related Work

Over the years, there have been a lot of studies involving the use of predictive analytics to observe patterns in crime. Some of these techniques are more complex than others and involve the use of more than one datasets. Most of the datasets used in these researches are taken from the Open Data initiative [3] supported by the government. In this section we will study the various techniques used by different authors which will help answer questions such as: *What is the role of analytics in crime prediction?*, *What techniques are used for data preprocessing?* and *What are the classification techniques which have proved to be most efficient?*

3.1 Temporal and Spectral Analysis

A lot of research in the area of crime analysis and prediction revolves around the analysis of spatial and temporal data. The reason for this is fairly obvious as we are dealing with geographical data spread over the span of many years.

The authors of [19] have studied the fluctuation of crime throughout the year to see if there exists a pattern with seasons. In their research, they have used the crime data from three different Canadian cities, focusing on property related crimes. According to their first hypothesis, the peaks in crime during certain time intervals can be distinctly observed in case of cities where the seasons are more distinct. Their second hypothesis is that certain types of crimes will be more frequent in certain seasons because of their nature. They were able to validate their hypothesis using Ordinary Least Squares (OLS) Regression for Vancouver and Negative Binomial Regression for Ottawa. Since their research focused on crime seasonality, quadratic relationship

in the data was predicted. Crime peaks were observed in the Summer months as compared to Winter.

In a similar study, the authors of [20] have analyzed the crime data of two US cities - Denver,CO and Los Angeles,CA and provide a comparison of the statistical analysis of the crimes in these cities. Their approach aims on finding relationships between various criminal entities as this would help in identifying crime hotspots. To increase the efficiency of prediction, various preprocessing techniques like dimensionality reduction and missing value handling were implemented. In the analysis, they compared the percentage of crime occurrence in both cities as opposed to the count of crimes. Certain common patterns were observed in both the cities such as the fact that Sunday had the lowest rate of crime in both the cities. Also, important derivations like the safest and the most notorious district, were noted. Decision Tree classifier and Naive Bayes classifier were used.

L. Venturini *et al.* [21], in their paper have discovered spatio-temporal patterns in crime using spectral analysis. The goal is to observe seasonal patterns in crime and verifying if these patterns exist for all the categories of crime or if the patterns change with the type of crime. The temporal analysis thus performed highlights that the patterns not only change with month but also with the type of crime. Hence, the authors of [21] rightly stress the fact that models built upon this data would need to account for this variation. They have used the Lomb-Scargle periodogram [22] to highlight the seasonality of the crime as it deals better with uneven or missing data. The AstroML Python package was used to achieve this. In their paper they have described in detail how every category of crime performs when the algorithm is applied to the data. Further, the authors suggest that researchers should focus on the monthly and weekly crime patterns.

3.2 Prediction using Clustering and Classification techniques

The authors of [23] have described a method to predict the type of crime which can occur based on the given location and time. Apart from using the data from the Portland Police Bureau (PPB), they have also included data such as ethnicity of the population, census data and so on, from other public sources to increase the accuracy of their results. Further, they have made sure that the data is balanced to avoid getting skewed results. The machine learning techniques that are applied are Support Vector Machine (SVM), Random Forest, Gradient Boosting Machines, and Neural Networks [23]. Before applying the machine learning techniques to predict the category of the crime, they have applied various preprocessing techniques such as data transformation, discretization, cleaning and reduction. Due to the large volume of data, the authors have sampled the data to less than 20,000 rows. They used two datasets to perform their experiments - one was with the demographic information used without alterations and in the second case, they used this data to predict the missing values in the original dataset. In the first case, ensemble techniques like as Random Forest or Gradient Boosting worked best, while in the second case, SVM and Neural Networks showed promising results.

Since a smart city should give importance to the safety of their citizens, the authors of [2] have designed a strategy to construct a network of clusters which can assign police patrol duties, based on the informational entropy. The idea is to find patrol locations within the city, such that the entropy is maximized. The reason for the need to maximize the entropy is that the entropy in this case is mapped to the variation in the clusters, i.e. more entropy means more cluster coverage [2]. The dataset used for the research is the Los Angeles County GIS Data. The data has around 42 different crime categories. Taking the help of a domain expert, the authors

have assigned weights to these crimes based on the importance of the crime. Also, the geocode for each record is taken into consideration and the records that do not have a geocode are skipped. Because the authors in [2] are trying to maximize the entropy in this case, consider the equation (3)

$$H_{c1} = -p(c_1)\ln p(c_1) \quad (3)$$

The probability $p(c_1)$ is defined as the ratio of weight of the centroid of the crime to the weight of the system, plus the ratio of the quickest path between two centroids, to the quickest path in the whole system.

The authors of [24] have taken a unique approach towards crime classification where unstructured crime reports are classified into one of the many categories of crime using textual analysis and classification. For achieving this, the data from various sources including but not limited to the databases which stores information about traffic, criminal warrants of New Jersey (NJ) and criminal records from NJ Criminal History was combined and preprocessed. As a part of the preprocessing activity, all the stop words, punctuations, case IDs, phone numbers and so on were removed from the data. Following this, document indexing is performed on the data to convert the text into its concise representation. In order to identify the topics or specific incident types from the concise representation, the authors used Latent Semantic Analysis (LSA). Next, similarity between these topics was identified using the Topic Modeling technique where the closer the score is to 1, the more similar it is to the topic which was followed by Text Categorization. The classification methods used in this research were Support Vector Machines (SVM), Random Forests, Neural Networks, MAXENT (Maximum Entropy Classifier), and SLDA (Scaled Linear Discriminant

Analysis). However, the authors observed that SVM performed consistently better of them all.

3.3 Hotspot Detection

A crime hotspot is an area where the occurrence of crime is high as compared to the other locations [25]. Many researchers have taken an interest in determining crime hotspots from the given dataset. The authors of [25] mainly discuss two approaches for detecting hotspots - circular and linear. The authors also discuss the fundamentals of Spatial Scan Statistics which is a useful tool for hotspot detection. The results on the Chicago crime dataset are also discussed in detail using both the approaches.

CHAPTER 4

Design and Implementation

The fundamental goal of the project is to build a model such that it can predict the crime category that is more likely to surface given a certain set of characteristics like the time, location, month and so on. We will also take the help of statistical and graphical analysis to help determine which attributes contribute to the overall improvement in the log-loss score.

4.1 Overview of the dataset

The data used in this research project is the San Francisco crime dataset made available by the San Francisco Police Department on the SF Open Data website [3], which is a part of the open data initiative. The dataset consists of the following attributes:

- IncidntNum : It is a numerical field. Denotes the incident number of the crime as recorded in the police logs. It is analogous to the row number.
- Descript: It is a text field. Contains a brief description about the crime. This field provides slightly more information than the *Category* field but is still quite limited.
- DayOfWeek: It is a text field. Specifies the day of the week when the crime occurred. It takes on one of the values from: *Monday, Tuesday, Wednesday, Thursday, Friday, Saturday, Sunday*
- Date: It is a Date-Time field. Specifies the exact date of the crime.

- PdDistrict: It is a text field. Specifies the police district the crime occurred in. San Francisco has been divided in 10 police districts. It takes on one of the values from: *Southern, Tenderloin, Mission, Central, Northern, Bayview, Richmond, Taraval, Ingleside, Park*
- Resolution: It is a text field. Specifies the resolution for the crime. It takes one of these values: *Arrested, Booked, None*
- Address: It is a text field. Gives the street address of the crime.
- X: It is a geographic field. It gives the longitudinal coordinates of the crime.
- Y: It is a geographic field. It gives the latitudinal coordinates of the crime.
- Location: It is a location field. It is in the form of a pair of coordinates, i.e. (X, Y)
- PdlId: It is a numerical field. It is a unique identifier for each complaint registered. It is used in the database update or search operations.
- Category: It is a text field. Specifies the category of the crime. Originally, there are 39 distinct values (such as *Assault, Larceny/Theft, Prostitution, etc.*) in this field. It is also the dependent variable we will try to predict for the test set.

There are about 1.4 million rows in the dataset and the size of the dataset is approximately 450 MB. It contains data from the year 2003 to (February) 2018. A snapshot of the actual dataset [3] is shown in Figure 5.

IncidentNum 160919032 160920976	Category VANDALISM ASSAULT	Descript MALICIOUS MISCHIEF, VANDAL THREATS AGAINST LIFE	DayOfWeek Friday Saturday
Date 11/11/16 11/12/16	Time 7:00 2:58	PdDistrict MISSION CENTRAL	Address 2600 Block of MASON ST FILLMORE ST / GEARY BL
X -122.4052518 -122.4140032	Y 37.751525 37.8079695	Resolution NONE ARREST, BOOKED	Location (37.75152495730467, -122.4052517658 (37.80796947292687, -122.4140031783
PdId 16091903228160.00 16092097619057.00	San Francisco Police Complaints dataset (2003 - 2018)		

Figure 5: Snapshot of the actual Dataset

4.2 Data Preprocessing

The data made available by the San Francisco Police Department is mostly complete with no Null values. However, there are a few outliers which have been handled. This will be explained in detail in the subsequent sections. The dataset provided a lot of potential to extract more meaningful information from the existing columns. Hence, a few columns have been added or transformed to improve the score of the resulting prediction.

4.2.1 Preprocessing using Apache Spark

As explained in the previous chapter, using Apache Spark has a lot of advantages, especially in terms of distributed and parallel processing. It can also significantly decrease the processing time required to process such a huge volume of data. Although the use of Apache Spark does not necessarily make a huge difference for this dataset because of its small size, this technique can be easily modified to work on data of a much larger scale spanning multiple distributed nodes.

The implementation of the rest of the project has been done using Python and hence we have used the PySpark distribution of Spark for preprocessing.

First a *SparkContext* object is created which informs Spark how it can access the cluster or data. Following this, we define a *SQLContext* object to be able to utilize Spark for handling structured data. All the data which is read by the *SQLContext* object will be of the type *DataFrame*. A *DataFrame* is conceptually equal to a table in the relational database.

If the source of the data is neither HDFS or a Hive table, then the source can be specified manually as:

```
sqlContext.read.load('path_to_file', format='com.databricks.spark.csv')
```

You can now perform the necessary tasks on this dataframe. Once the desired result is achieved, the dataframe can be written to a new CSV file using the following format:

```
dataframe_name.coalesce(1).write.option("header", "true").csv('filename', header = "true", mode = "overwrite")
```

Here, `coalesce(1)` specifies that the entire Spark output should be written to a single output file instead of creating multiple reducer output files. The *header* specifies if the dataframe headers should be included in the CSV file to be created. The *mode* specifies if the file can be overwritten or not. By default, the file cannot be overwritten.

4.2.2 Techniques used for preprocessing

The original dataset is modified to create a new dataset where new columns are added, existing columns are transformed and outliers are handled. This gives much

better results than the existing data. The decision to add or transform columns has been taken by studying the graphical analysis which has been performed on the data prior to building a model.

4.2.2.1 Data Cleaning

One of the primary steps of Data Cleaning is Outlier Handling. In the San Francisco Crime dataset, there are a total of 196 outliers as the longitudinal coordinate exceeds the minimum boundary of San Francisco. The outliers were filtered by the code below:

```
dataframe.filter(dataframe.X < -122.3549)
```

where X is the longitudinal coordinate.

The next step in Data Cleaning is taking care of incorrect or missing data. Although the dataset does not contain Null values or missing values, the Category column does contain a few columns which have been incorrectly labeled like the *TREA* category which should actually be *TRESPASSING*.

There are 39 distinct categories in the dataset. However, some of the categories are very similar to each other. For example, when the Category column contains values or keywords like: *INDECENT EXPOSURE* or *OBSCENE* or *DISORDERLY CONDUCT* then return *PORNOGRAPHY/OBSCENE MAT*. The decision on which categories should be clubbed together is taken by looking at the Description column of the dataset which provides more information on what the corresponding Category column represents. The complete list is presented for reference in Table 1.

Original Category containing	New Category
Weapon Laws	Deadly Tool Possession
Bad Check, Counterfeiting, Embezzlement	Fraud/Counterfeiting
Suspicious Occ	Suspicious Person/act
Warrants	Warrant Issued
Vandalism	Arson

Table 1: Combining Similar Categories

4.2.2.2 Data Transformation

Data transformation is one of the most important data preprocessing techniques. Usually, the data is originally present in the form that makes more sense if it is transformed. In this case, the main transformations performed are as follows:

1. Extracting Information from Other Attributes:

On taking a closer look at the Description column, it is observed that it contains a lot of useful information which has not been captured in the Category column. For example, although the Description column explains that the crime has something to do with *WEAPON LAWS*, the Category column has classified it under *OTHER OFFENSES*. This might cause us to miss out on significant information. Hence, we extract such information from the Description column and rename the categories in the Category column.

The complete list is shown in Table 2 for reference.

2. Feature Extraction:

There a lot of features like Address, Time, Date, X and Y which can be transformed into new features that hold more meaning as compared to the existing

Description Containing	New Category
License, Traffic, speeding, Driving	Traffic Violation
Burglary Tools, Air Gun, Tear Gas, Weapon	Deadly Tool Possession
Sex	Sexual Offenses
Forgery, Fraud	Fraud/Counterfeiting
Tobacco, Drug	Drug/narcotic
Indecent Exposure, Obscene, Disorderly Conduct	Pornography/obscene Mat
Harassing	Assault
Influence Of Alcohol	Drunkenness

Table 2: Extracting Information from Description Column

ones. Hence, all of these features have been used to generate new features and some of these old features have been eliminated.

Address to BlockOrJunc: In its original form, the Address feature has a lot of distinct values. Thus, if given a logical consideration, it is not hard to realize that the exact address of the crime might not be repeated or be useful in predicting the type of crime in the future. However, this column can be used to see if the crime occurred on a street corner/junction or on a block. We can also check if there exists a pattern among certain types of crime to occur more frequently on a street corner rather than a block. To achieve this, a simple check of whether '/' occurs in the address or not, is performed. If it does contain the same, it means that the crime occurred on a corner and we return 1, otherwise it is a block and we return 0. The pseudocode is shown below:

```

if address contains '/' then
    return 1
else
    return 0

```

end if

Time to Hour: The Time feature is in the Timestamp format. It would be interesting to observe patterns in crime by the hour. Hence the Hour field is extracted from the Time field. It is worth noting that if the minute part is greater than 40, i.e. if the time is for example, 12:42, then the hour is rounded off to 13, otherwise it would be 12. The pseudocode is as shown below:

```
if minute > 40 then
    return (hour + 1) % 24
else
    return hour % 24
end if
```

Date to Season, Day, Year and Month: The Date field is a very important one for prediction. Using this single field, we are able to extract four features. Spark provides inbuilt methods to extract the Day, Month and Year from the Date and hence our script makes use of the same.

After extracting the Month from the Date, we make use of this feature to extract the Season. The pseudocode is shown below:

```
if month = 12 or month = 1 or month = 2 then
    return Winter
else if month = 3 or month = 4 or month = 5 then
    return Spring
else if month = 6 or month = 7 or month = 8 then
    return Summer
else
```

```
    return Fall
end if
```

X and Y to Grid: The X and the Y coordinates provide the exact location of the crime. However, we can see some interesting patterns on dividing the entire San Francisco area into grids of 20 X 20. This is inspired from the author of xyz, which gives specific details on the formula used for generation of these 400 cells.

4.2.2.3 Data Reduction

As previously mentioned, there are 39 categories on crime in the original dataset. Some of them include labels like *NON-CRIMINAL*, *RECOVERED VEHICLE* and *SECONDARY CODES*. Since we are trying to predict the future occurrences of crimes, it is essential to have categories pertaining to actual criminal activities. But the above labels do not provide any additional information to help us achieve our goal. Thus, these categories are completely filtered out from our dataset. This reduces the number of rows from about 2.1 million to about 1.9 million 38,000 after all the preprocessing. But with more data in the future, the predictions are expected to improve.

4.3 Software and Technologies Used

This project is implemented in Python (version 3.6.4). The other libraries used throughout the project are described below:

PySpark: Apache Spark is a high performance, cluster-computing, open source framework for data analytics and is capable of handling big data. It is known for its ability to implicitly handle parallelism and for being fault tolerant. Spark's Python

API, which is known as PySpark exposes the Spark programming model to Python. In this project, PySpark was used for data preprocessing. The advantage of this approach is that, large amount of data is processed quickly and the existing code can be easily modified to support distributed big data in the future, if necessary.

Pandas: Pandas is an open source library that provides tools for data mining and analysis using Python. It is mainly used in this project to prepare the data for consumption by specific machine learning algorithms.

NumPy: NumPy is a Python library that can handle multidimensional data and perform scientific and mathematical operations on the same. NumPy was used in this project as an accessory to the Pandas library to perform some basic mathematical operations.

scikit-learn: scikit-learn [16] is an open-source Python machine learning library which provides numerous classification, regression and clustering algorithms. This library was used in this project to perform the actual task of model building and prediction. It provides a variety of evaluation metrics to validate the performance of the model, which makes it a valuable tool.

Tableau: Tableau is a powerful data analytics tool which is used for building interactive dashboards. Tableau was mainly used in the project to generate interactive graphs and observe patterns in the data. This information proved to be useful in determining the features that could contribute well to the actual model building. It also provides a rich map interface for geographical data.

CHAPTER 5

Experimental Results

5.1 Comparison of this approach with existing results

In this section a comparative study of our new approach and the results of existing work, as mentioned in the related work section, is described.

First, we go on to describe the features used for building the various models in other researches. They are assigned labels of the form *Source 1*, *Source 2* and so on for easy reference in the subsequent sections.

As seen in most of the cases the results of the current approach are marginally better than the previous approaches, except in case of Logistic Regression, where the results of Source 4 are better.

Source 1: The authors of [26] have used the features *DayOfWeek*, *PdDistrict*, *X*, *Y*, *Month*, *Year*, *Hour* and *Grid(of 8 X 8)* in some combination, for the prediction.

Source 2: *Hour*, *Month*, *District*, *DayOfWeek*, *X*, *Y*, *Street No.*, *Block* and 3 components of *PCA* are used in the research by the authors of [27]

Source 3: In the PhD research by X. Wu [28], the attributes/features used for prediction are *Year*, *Month*, *Hour*, *DayOfWeek*, *PdDistrict*, *X*, *Y* and *Block/Junction*

Source 4: In another independent project by an author [29] the features used for prediction are *Hour*, *DayOfWeek*, *Month*, *Year*, *PdDistrict*, *Season*, *BlockOrJunction*, *CrimeRepeatOrNot*, *Cell* and *39DVector*

Another important aspect, left out by the previous papers on crime classification

Algorithm	My Results	Source 1	Source 2	Source 3	Source 4
Random Forest	2.2760	2.496	2.366	2.45	-
Naive Bayes	2.5008	2.5821	2.6492	-	-
Logistic Regression	2.4042	2.5516	-	-	2.365
KNN	2.4634	-	2.621	25.17	-
Decision Tree	2.3928	2.508	-	-	-

Table 3: Results of Experiments

in San Francisco, is the issue of data imbalance. The dataset being worked with is highly skewed. The sum of the distinct categories of crime in the dataset, is illustrated in the figure 6.

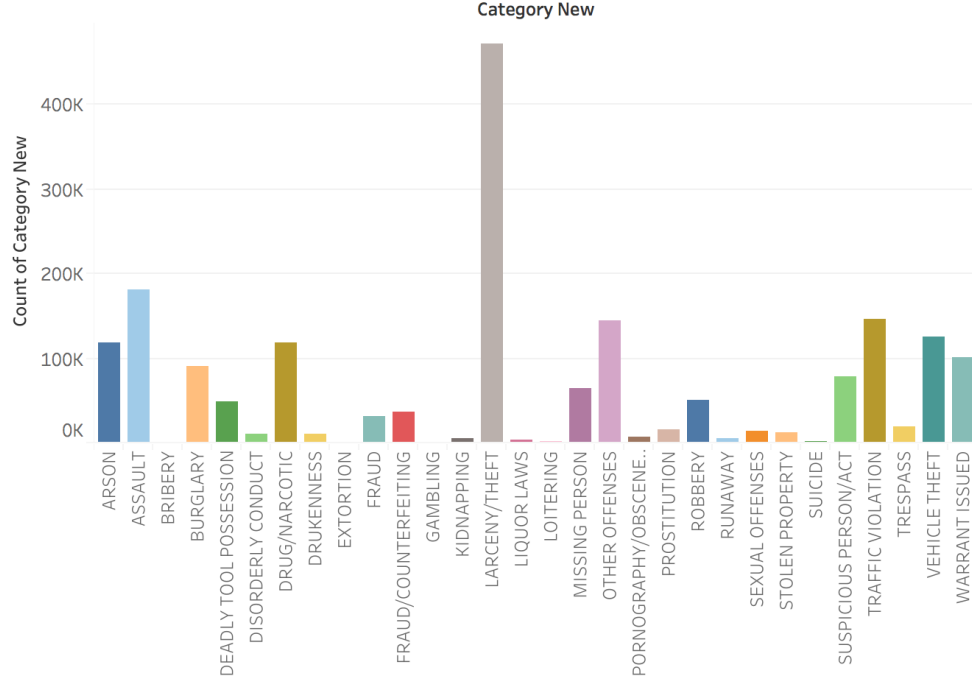


Figure 6: Count of Distinct Categories in the Dataset

5.2 Results of Graphical Analysis

In this section, we would look at the results of graphical analysis conducted which also helped decide what features to include for predictions. Some of these graphs show interesting patterns in crime, which might not be apparent otherwise.

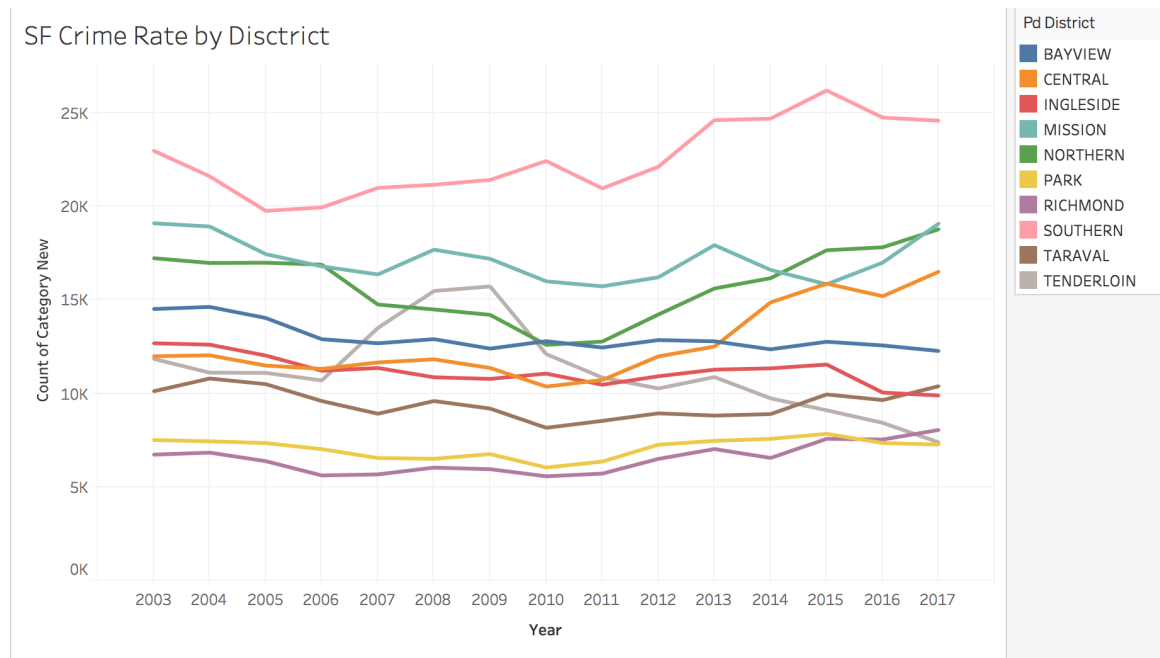


Figure 7: Rate of Crime per District by Year

Figure 7 shows the trend of the crime over the years in various districts of San Francisco. These are the Police Districts and each of those include many other city districts. Here, you can see that the crime in *SOUTHERN*, *CENTRAL* and *NORTHERN* districts is on the rise. Whereas, crimes in *TENDERLOIN* and *INGLESIDE* have seen a fall in their crime.

If you look at Figure 8, you can see that there is a clear pattern in crime and the hour of the day. Generally, crime rate is low in the wee morning hours from around 3:00 AM to 6:30 AM and it rises to its peak in the evening rush hours, i.e. from 4:30 PM to 7:00 PM and is generally high at night. However, it would be really interesting

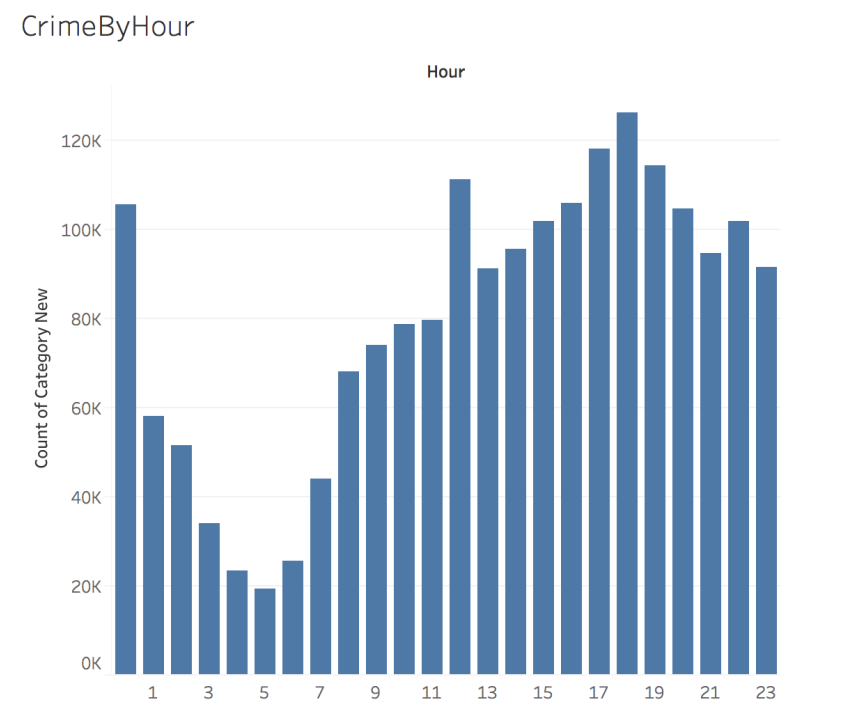


Figure 8: Rate of overall crime every Hour

to see if this pattern is followed by all the different types of crime. For this, we plot graphs for the top four crimes that we found interesting.

Below in Figure 9, is the graph of Theft/Larceny per hour. It pretty much follows the trend in the previous graph.

Next, we plot a graph of the crime type *Prostitution* per hour. As seen in Figure 10, there are clear areas where Prostitution is high as compared to others and we can also see that Prostitution is higher during midnight and late hours which might be expected. However, it is also very high around 11:00 AM in the Central district, which is unusual and can be further looked into, in the future.

In the Figure 11, we can see that the Drug/narcotics related crimes were highest in the year 2009 followed by 2008. Anyone even slightly familiar with San Francisco

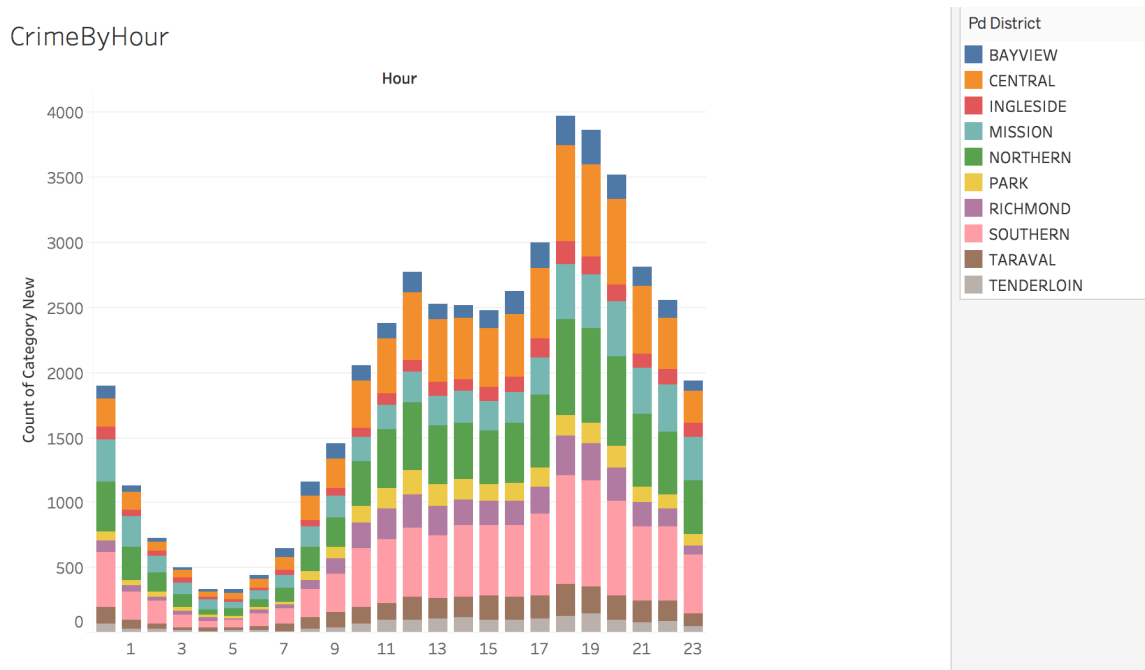


Figure 9: Rate of Theft/Larceny by the Hour

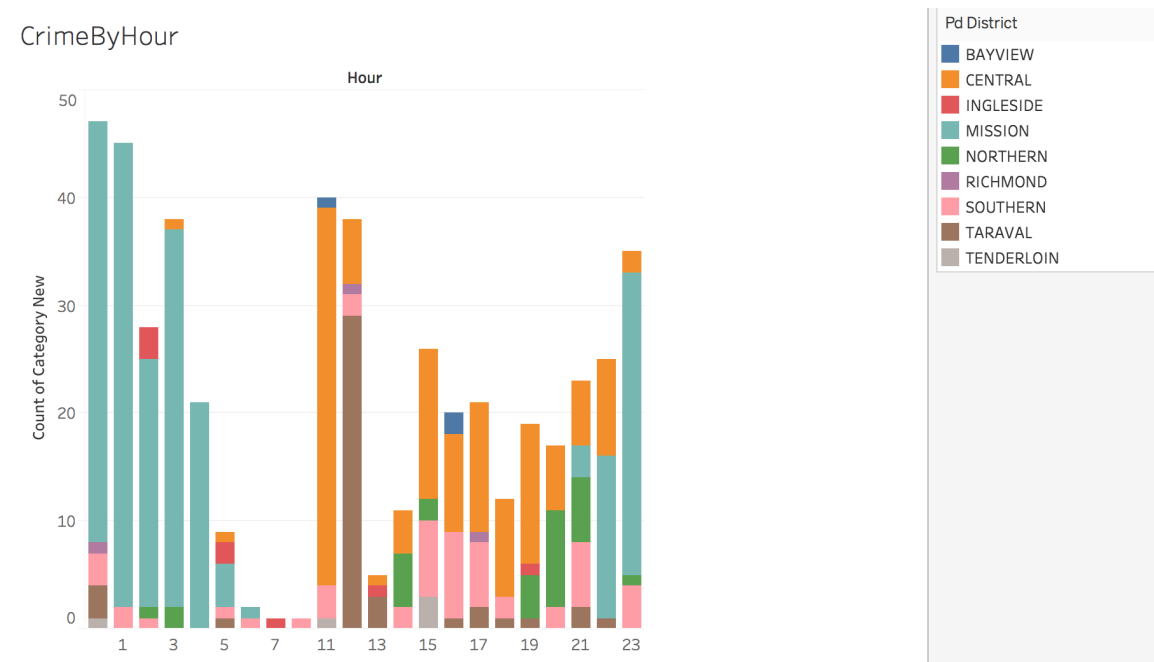


Figure 10: Rate of Prostitution by the Hour

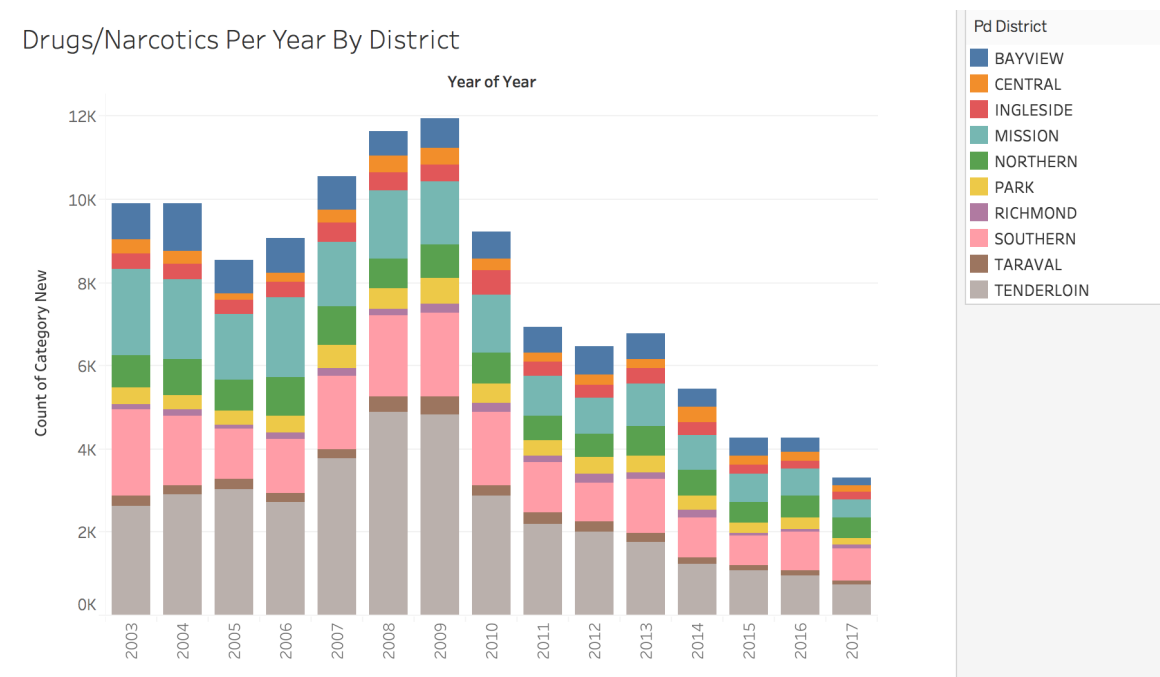


Figure 11: Sum of Drugs/Narcotics cases per Year

might mention that the Tenderloin is one of the most notorious districts in San Francisco with a high crime rate, especially, with high rate Drugs and Narcotics related crimes.

From the Figure 11 we can see that Tenderloin district has the highest number of Drug related crimes till 2009. However, in the recent years, these crimes have seen a huge dip, going down by more than 50% since 2009.

A great way to study the growth or decrease in rate of crime is by using area charts. An area chart is another way to look at the growth (or fall) rate in the data. In the Figure 12 we study the rise in the number of thefts over the years in most of the districts in San Francisco, except Tenderloin and Taraval.

While, on the other hand, on plotting the area chart of Drugs and Narcotics as shown in Figure 13 we can see a clear decrease in these crimes in San Francisco.

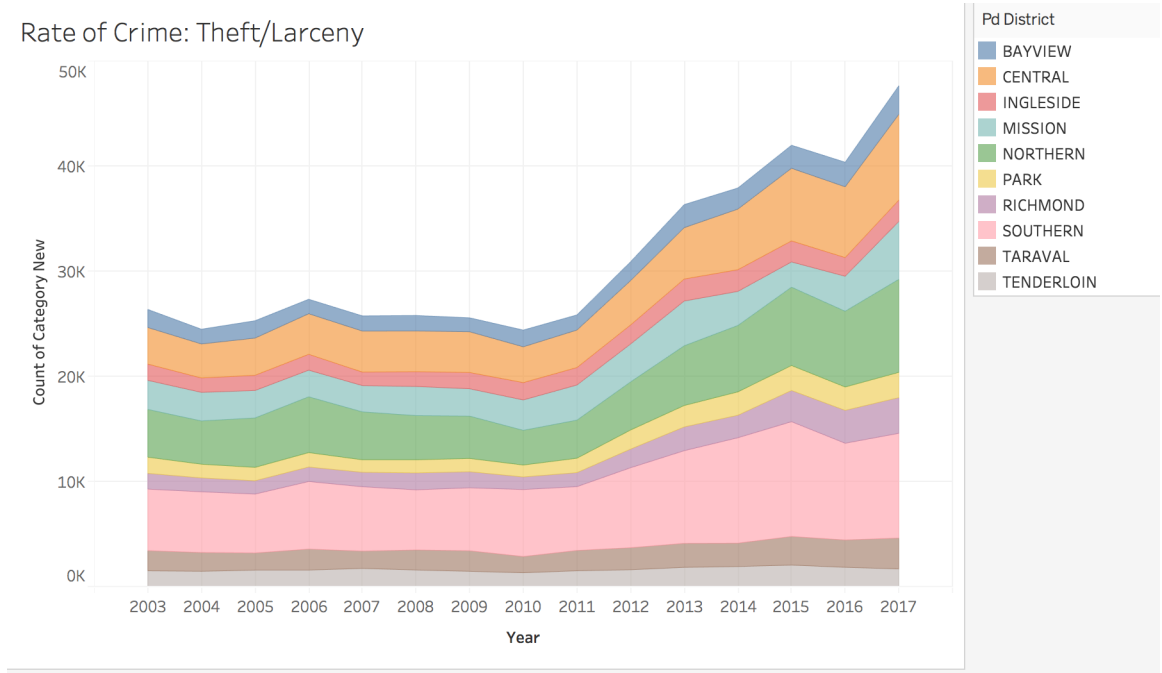


Figure 12: Area of Theft/Larceny by the Year

Another important thing to note is that only calculating the Log Loss score might not be enough to evaluate the efficiency of the model. We need the model to correctly identify maximum samples but at the same time, we want those correctly identified samples to include the minority classes as well. Also, it is expected from a good model that the minority classes identified are identified correctly every time. Thus, we need to calculate the Recall and Precision of the classifiers.

It is interesting to observe that the data, even after preprocessing, is imbalanced with the LARCENY/THEFT category acting as the majority class. We tried three techniques to handle the imbalance - Oversampling the minority classes, oversampling the majority class and adjusting weights on the classifiers. But these did not show a significant improve in the Recall or Precision scores. Hence, the following preprocessing was performed on the already preprocessed data:

Rate of Drugs/Narcotic

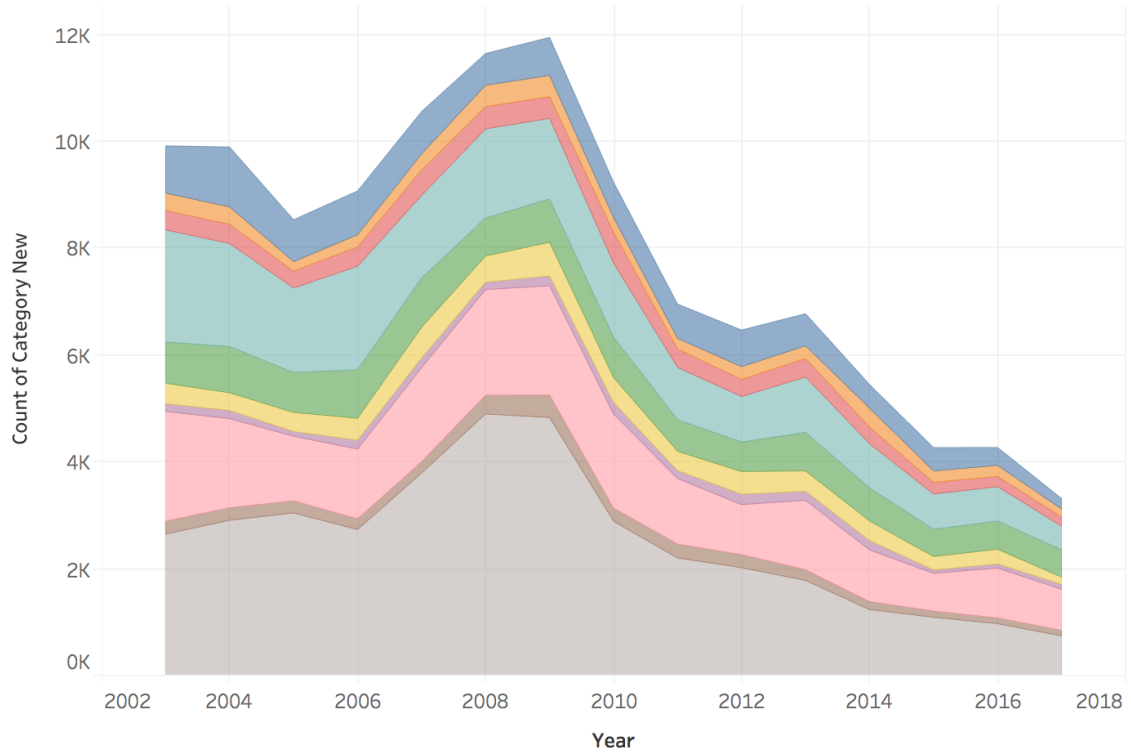


Figure 13: Area of Drugs/Narcotics by the Year

1. The LARCENY/THEFT category was split taking into consideration the Description column. It was observed that separating out the samples with *Grand Theft From Auto* in their description proved to be a good split. The resulting classes were LARCENY/THEFT and THEFT FROM AUTO.
2. Combined classes with less than 2000 samples into OTHER OFFENSES category.
3. Created a new category called VIOLENT/PHYSICAL CRIME which includes former categories of ARSON, WEAPON LAWS, VANDALISM and instances of ROBBERY where physical harm or guns were involved.

This made the data more balanced than the earlier set and showed improved

Recall and Accuracy for the two algorithms it was tested on - Decision Tree and Random Forest. These results are illustrated below

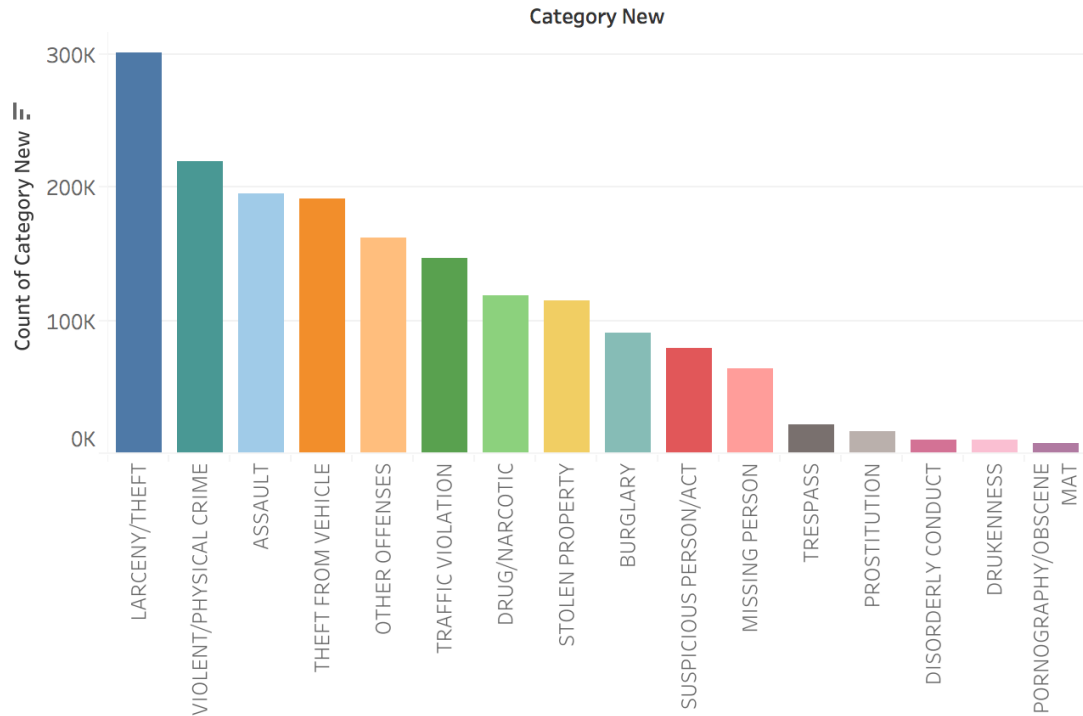


Figure 14: More Balanced Dataset

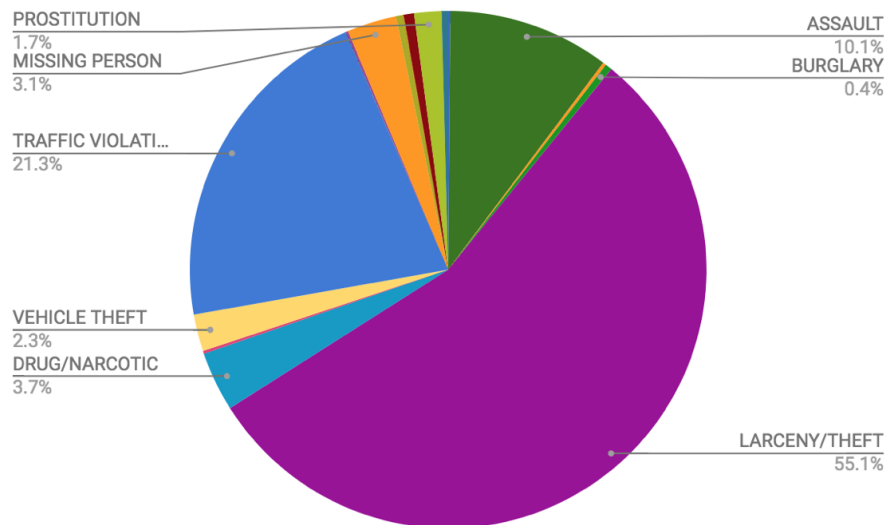


Figure 15: Recall for old preprocessing

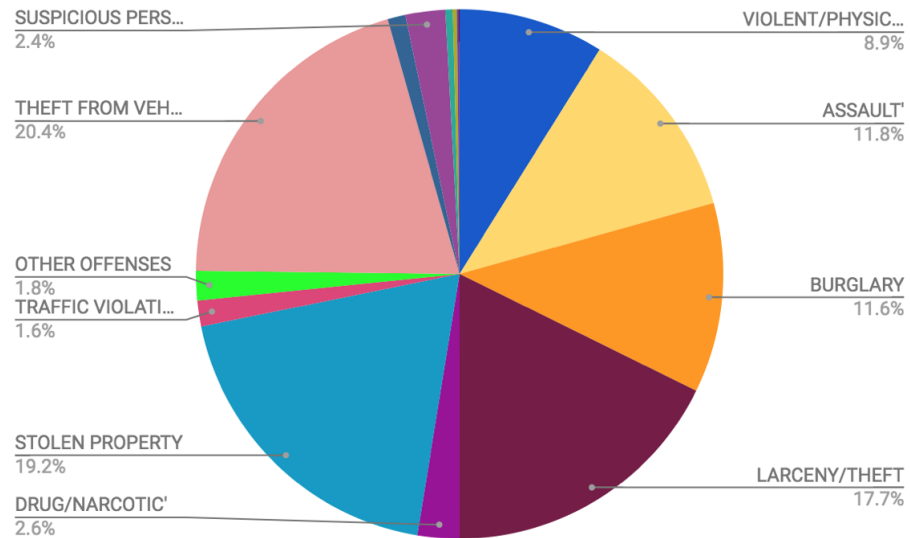


Figure 16: Recall for more balanced dataset

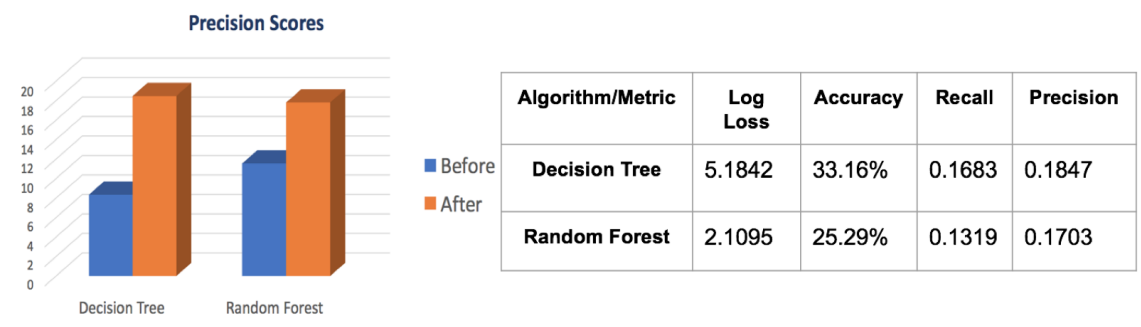


Figure 17: Comparison of Precision scores

CHAPTER 6

Conclusion and Future Work

In this research, a detailed analysis of various types on crimes in San Francisco was conducted. Also, prediction models were trained using 5 machine learning algorithms and the results were compared with the previous research conducted in this domain. A study of how the data imbalance affects prediction is specified and also an approach to tackle that is discussed. As a part of the future work, using the preprocessing done in this research, Neural networks can be trained and their results can be compared with the existing ones. It would be interesting to see if more even class splits can be achieved by using additional dataset along with the crime dataset. It would help us see if there are more factors that contribute to the crime, like population data, housing data and transportation data to name a few.

Also, this same model can be tested on other crime datasets like the Chicago crime data, which is another well known dataset. It would be really interesting to see how the crimes in other cities compare to the crimes in San Francisco.

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