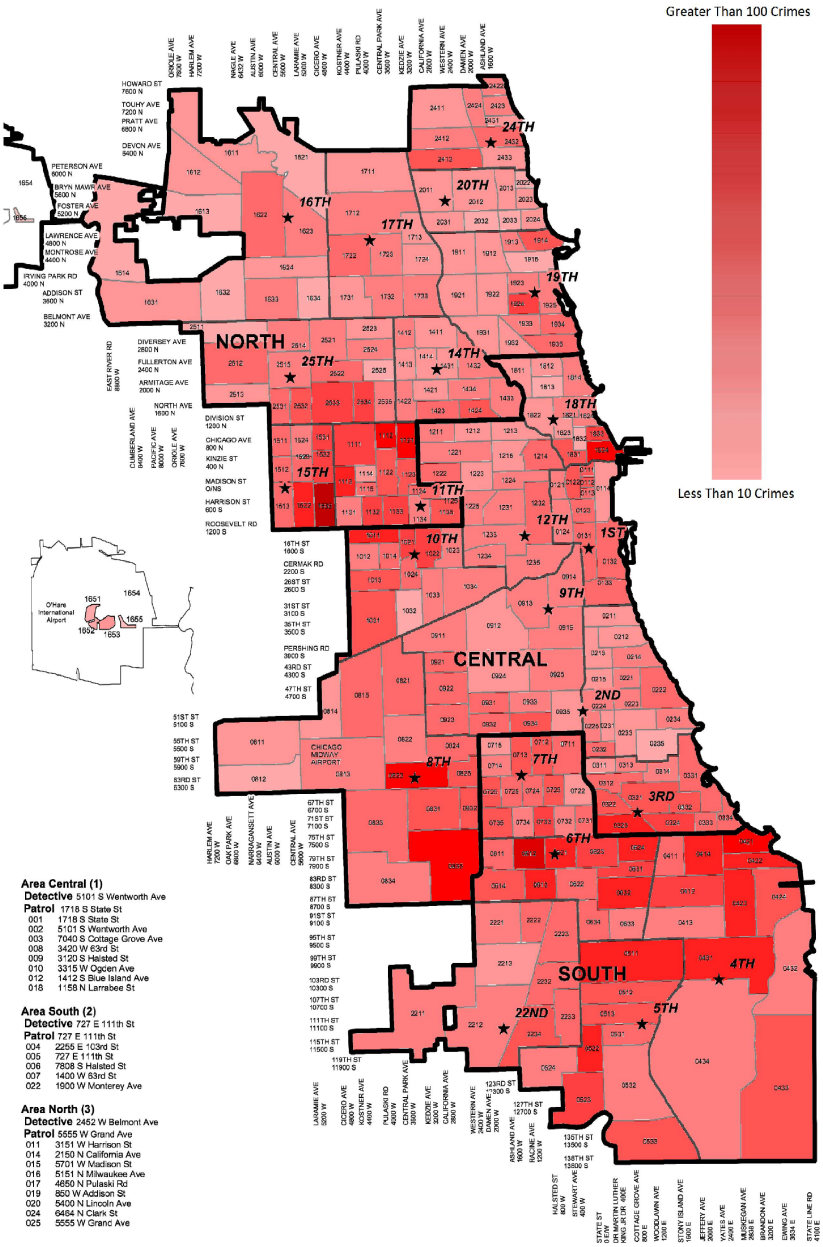
HiMCM Problem B 2015
Team 5549



Cops And Robbers (And Mathematicians):

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Introduction:

Don't drop the beat. We'll need it soon.

A beat, or the path and schedule a policeman follows, was invented after the heavy urbanization of the industrial revolution caused increased crime in cities. Local police forces needed to work more efficiently to combat crime, so they designated specific areas and times that would be patrolled. My City, a prosperous and diverse city that houses 2.8 million people, is separated into 274 beats. My City's finest have provided a list of all crimes that occurred over the course of two weeks - July 5, 2014 to July 18, 2014 - and it was our job to analyze and use this data to evaluate the city's safety.

General Assumptions:

Assumption 1

The data collected for My City in the two weeks provided was representative of an entire year.
Justification - It would have been impossible to account for every factor that could have changed the crime rate over the course of the year, so it was necessary to extrapolate the data provided in order to create a model that was comparable to real-world statistics.

Assumption 2

The crime rates provided by the NYCdata database remain consistent enough for each city between years that values from 2013 can be compared to the 2014 crime data for My City.

Justification - On account of their large populations, crime per capita in large cities does not change significantly over a single year. Therefore, any difference between the 2013 and 2014 crime statistics would be negligible.

Assumption 3

All counts of criminal sexual assault listed in the My City data were forcible rape.
Justification - There was no primary or secondary description for rape in the data provided. To address this problem, the category listing that was closest to rape in terms of both description and actual statistics was used.

Assumption 4

Aggravated assault and aggravated battery had equal severity levels and could be grouped together when analyzing data.
Justification - These two categories were grouped together in every source that was found, so it was justifiable to do the same for the My City data in order to make it more easily comparable to those sources.

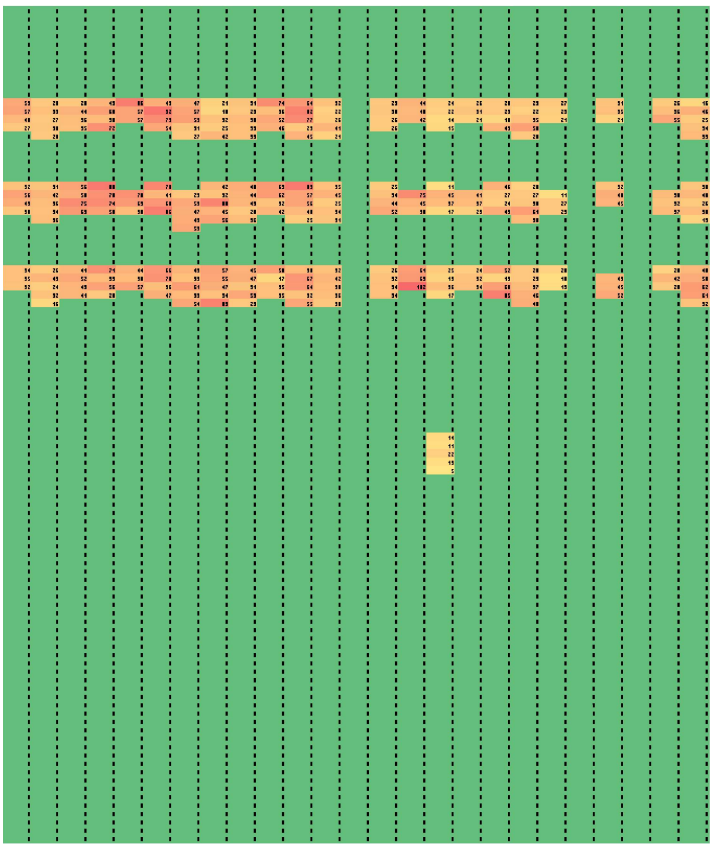
Assumption 5

The safety rating created only needs to be dependent on crime.
Justification - While there were other factors that could be included in a safety rating (medical care, infrastructure, etc.), the data provided for this problem was entirely focused on crime.

Understanding the Data:

Heat Map I

First, we attempted to create a “heat map” of the frequency of crime in different locations of the city. This would allow us to visually assess how much of the city was being affected by crime, and which crimes were more prevalent. To do this, a grid was created in excel in which each cell represented one of the beats provided. The color of the cell was determined by the number of crimes in that beat. It was initially assumed that the city’s beats were in a grid pattern, and that in total there were beat zones numbered from 100 to 2599. The first heat map created is shown below.

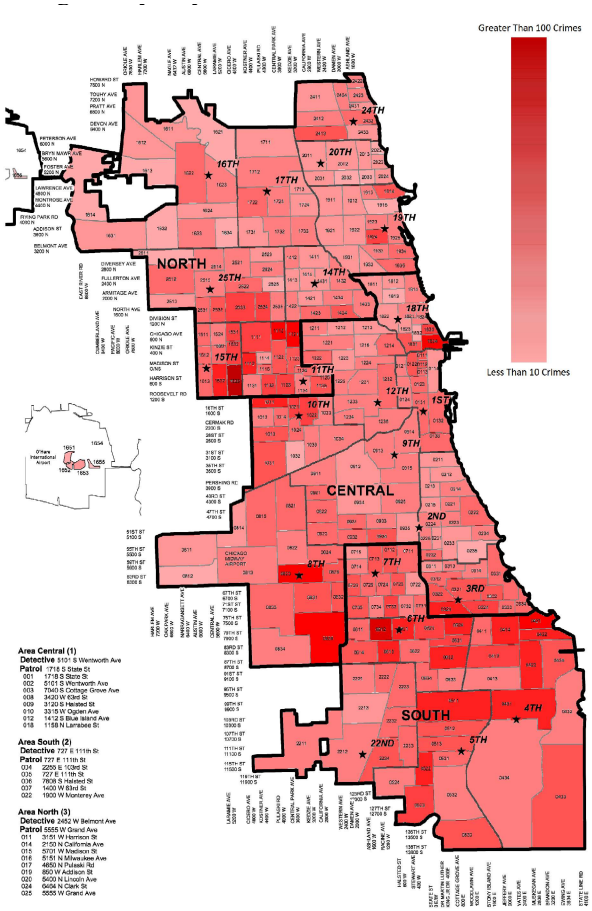


Initial Research

To better understand the research given and to also apply the research to more realistic situations, real beat maps of cities were analyzed. One such city was Chicago, and it was discovered that the beats provided were identical to those of Chicago. This led our group to conclude that My City has an identical layout to Chicago. It was decided to use a map of Chicago to create a crime heat map.

Heat Map II

After concluding that My City closely resembled the city of Chicago, a currently existing map of beats in Chicago was edited to display a heat map of crime occurrences for every beat in My City. This helped to create insight into how to further the understanding of the safety of My City. The beats from the data provided were given a realistic orientation through relation to an actual city, and, along with their corresponding crime counts, provided visual insight for crime distribution within My City. Also, the restructured data offered a segue into developing a Safety Rating for My City.



Goals of this Paper:

The goal of this paper was to analyze two weeks' worth of My City's crime data and use it to create a safety rating of the city. We used to main strategies to accomplish this, internal and external analysis. The internal strategy ranked each beat's safety to determine which parts of the city were safest and most dangerous. The external strategy ranked My City's violent crimes against those of other cities to determine how the whole city compared to others.

Model I:

Defining Safety

Before creating a ranking system with which the safety of My City could be assessed, the idea of "safety" needed to be defined. For the purpose of our initial model, a "safe" city was one in which you had a small likelihood of being effected by crime. The likelihood of any individual being effected by a crime could be approximated by the total number of crimes occurred divided by the total population. Therefore, a safe city was one with little crime relative to its population size.

Procedure

In this model, the approximate number of violent crimes per 100,000 people anually in My City was compared to the same statistic of other major cities.

Data for violent crimes per year was obtained from Baruch College's NYCdata Database. It was in the format of total violent crimes per 100,000 people per year (comprised of the sum of the aforementioned four groups). In order to compare My City's crime to other cities', an estimation was made for each violent crime on the number of occurrences per 100,000 people per year. The amount of each violent crime that occurred over the two-week period was counted. Because those crimes occurred over the span of 14 days, the approximate number of occurrences per year was calculated by dividing the quantity by 14 and multiplying by 365. The calculated value was the number of occurrences per the total population per year. By multiplying it by 100,000 and dividing by the total population, the approximate number of each violent crime per 100,000 people per year was created.

Example: Calculating My City Homicides per 100,000 people anually. There were 20 homicides in the recorded two-week period.

$$20 * \frac{365}{14} * \frac{100\,000}{2\,800\,000} = 19 \text{ homicides per 100,000 people anually.}$$

Below is the full list of compared cities and crime values. The number of violent crimes per 100,000 people per year was used as a measurement for safety, with smaller values representing higher safety. In this model, the safety of My City is greater than San Antonio, but less than New York City.

Violent Crimes per 100,000 People per Year	
Indianapolis, IN	1,232
Philadelphia, PA	1099.3
Houston, TX	962.7
San Francisco, CA	847.1
Dallas, TX	663.7
Phoenix, AZ	631.9
San Antonio, CA	630.7
My City	625.714
New York City, NY	623.9
Jacksonville, FL	620.3
Charlotte, NC	608
Los Angeles, CA	426
San Diego, CA	393
Austin, TX	363.5
San Jose, CA	324

Strengths and Limitations

Strengths: This model is simple to calculate, and uses easily accessible data, namely the violent crimes of each city per 100,000 people per year.

Limitations: The approximate values of each type of violent crime per 100,000 people per year was estimated using only 14 days of data provided. Therefore, the accuracy of the ranking derived from those values is limited. Additionally, the model treats all crimes equally; less severe crimes, like robbery, effect the overall ranking of the city as much as more severe crimes, like homicide.

Model II:

Specific Assumptions

-All criminals are first-time offenders.
-All homicides committed are first-degree murders.
-Robbers who used a firearm, cutting weapon, or other weapon brandished it but did not use it.
-Robbers who used strong-arm tactics caused bodily injury to an individual.
-Perpetrators of aggravated assault used a firearm and caused bodily harm to an individual.

Procedure

Understanding Crime Severity Index

While Model I provided a clearly understandable safety rating for each city, its use was limited because each crime, regardless of severity, effected the safety rating the same amount. Model II solves this issue by assigning each crime a "weight" based on severity, and multiplying that weight by the quantity of the offenses of that crime. In this way, several offenses of heinous crimes such as murder can change a city's ranking more than a greater number of offenses of a lesser crime, such as robbery.

In an effort to improve understanding of crime severity and change, the Statistical Society of Canada created an equation to calculate the Police-Reported Crime Severity Index, or PRCSI, of a location. Each crime has a quantity (the number of times it has been committed) and a weight (a mathematical value which is pre-defined and based on crime severity). The quantity of each crime is multiplied by its weight, and each product is added together. The sum of all of the weighted crime quantities is divided by the total population of that location, and multiplied by 100. The result is a value that more accurately represents the severity of crimes in an area, in comparison to the simple crime per 100,000 per year model, which regarded each crime with the same severity.

$$\overset{\text{Crime Severity Index}}{CSI} = \overset{\text{Sum for All Offenses}}{\sum_i} \overset{\text{Number of Offenses}}{q_i} \overset{\text{Weight of Offense}}{w_i} / \overset{\text{Total Population}}{pop}$$

Calculating Weight Values

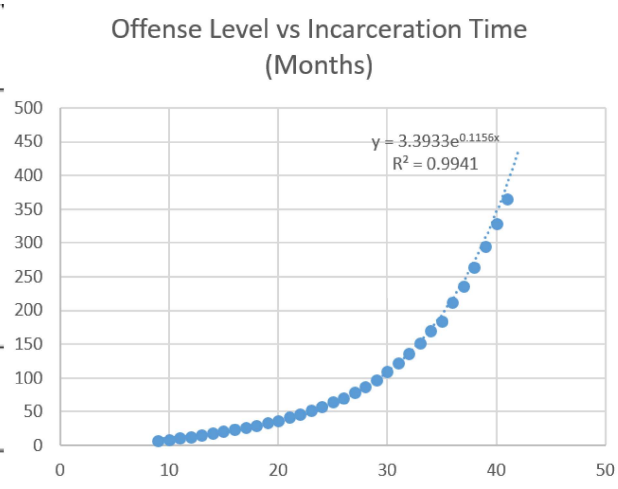
The most difficult step in completing this model was calculating the weights. The weights determined how much impact the quantity of a violent crime would have on the resulting safety index. In order to decide what weights each crime should have, the group researched how violent crime severity is regarded in US court cases.

The United States Federal Sentencing Guidelines (USFSG) assign each crime a value called a "base

offense level." Each crime is assigned a base offense level between 0 and 43, with 43 the most severe possible. To account for the differences of severity of court cases of the same crime, the offense level can be adjusted depending on the specific nature of that offense. The purpose of the offense level is to serve as a starting point for a judge to choose an incarceration time, as each offense level corresponds with a range of months during which it would be appropriate for the perpetrator to be incarcerated.

The base offense levels of violent crimes were used as the foundation for the weights. By graphing the offense levels and the mean value of the suggested range of incarceration provided by the USFSG, an exponential equation was found that relates offense level to number of months incarcerated.

Offense Level	I (0 or 1)
1	0-6
2	0-6
3	0-6
4	0-6
5	0-6
6	0-6
7	0-6
8	0-6
9	4-10
10	6-12
11	8-14
12	10-16



The equation for months served in terms of offense level is:

$$months = 3.3933 * e^{0.1156 * offenseLevel}$$

Just as the Statistical Society of Canada used the number of years incarcerated as a basis for weight, Model II used the number of months incarcerated. Because it was established that the number of months incarcerated could be found based on the offense level of a crime, the offense levels of each violent crime would need to be determined. However, a crime's offense level can vary on a case-by-case basis. Therefore, our group worked to determine the frequencies of different factors that effect the offense level of each violent crime, so that an average offense level could be created for each

.

Homicide:

The base offense level for first-degree murder was 43, the highest possible. However, the category of homicide also included second-degree murder, voluntary manslaughter, and involuntary manslaughter, each of which had different base offense levels. In the time allocated the relative proportions of each type of homicide was unable to be determined, so it was assumed that all homicides were first-degree murders. Nonetheless, this does match the data provided, as every homicide in My City was a first-degree murder. Therefore, the offense level of homicide was determined to be 43.

Forcible Rape:

The base offense level for forcible rape was 30. If, however, the victim was under the age of twelve, the offense value was 38. Because this shift was significant, it was factored into our model. The Bureau of Justice Statistics stated that 1.5% of rape victims were under the age of twelve. This means that 1.5% forcible rape cases had an offense value of 38, and the other 98.5% had an offense value of 30. A weighted average is found with the following equation:

Therefore, the average offense level of rape was determined to be 30.12.

Robbery:

The base offense level for robbery was 20. This value was adjusted by a number of factors established by the United States Sentencing Guidelines, including: If a firearm was brandished or possessed, the offense level was increased by 5; if a different dangerous weapon was brandished or possessed, the offense level was increased by 3; if anyone incurred bodily injury, the offense level was increased by 2. According to FBI statistics, in 41.4% of robberies the perpetrator used a gun. Assuming the criminal brandished it but did not fire, the offense level was 25. In 42.0% of the cases, strong-arm tactics (fighting without a weapon) were used. It can be assumed that the criminal would have had to first injure someone in order for the police to have determined that they were willing to use strong-arm tactics, which would have caused the offense level to be 22. In 7.9% of the cases, cutting weapons were used, and assuming they were brandished but not used, the offense level was 23. Similarly, in the remaining 8.8% of cases in which criminals used weapons not specified previously, it was assumed that they brandished but did not use their weapons. The offense level for these cases was also 23. The weighted average for all four scenarios would be:

$$(0.414)(25) + (0.420)(22) + (0.079)(23) + (0.088)(23) = 23.431$$

Therefore, the average offense level for robbery was 23.43.

Aggravated Assault:

The base offense level for aggravated assault was 14. Because aggravated assault is an attempt to cause serious bodily harm to another individual, it was assumed that the perpetrator would use a gun, an increase of 5, and cause some bodily harm, an increase of 2. Therefore, the offense level for aggravated assault was determined to be 21.

The adjusted offense levels for each violent crime category are as follows:

Homicide: 43
Forcible Rape: 30.12
Robbery: 23.43
Aggravated Assault: 21

Using the equation that relates number of months to offense number, the approximate sentencing time in months for each violent crime category can be found.

Homicide: $3.3933 * e^{0.1156*43} = 489.12\ months$
Forcible Rape: $3.3933 * e^{0.1156*30.12} = 110.35\ months$
Robbery: $3.3933 * e^{0.1156*23.541} = 51.58\ months$
Aggravated Assault: $3.3933 * e^{0.1156*21} = 38.45\ months$

While the Canada Society of Statistics multiplied the time incarcerated by the ratio of offenders incarcerated to determine the weights for their PRCSI equation, in the allocated time adequate statistics of the number of incarcerated offenders could not be found, and consequently the number of months incarcerated was used alone as the values for the weights of each violent crime.

Comparing CSI Values:

Approximated values for the total number of each violent crime in My City each year were used along with the weight of each violent crime and the population of My City to determine the city's Crime Security Index

(CSI). The CSI of My City is 20.42. Using violent crime data from other cities, we created a similar comparison between cities as in Model I.

	Murder	Rape	Robbery	Ag.Assault	Population	CSI
Indianapolis, IN	129	656	3800	5894	850220	65.645
Philadelphia, PA	247	1279	7562	7986	1553153	61.75042
My City	521	1121	10507	16894	2800000	56.07476
Houston, TX	214	618	9891	10270	2180606	49.43348
San Francisco, CA	48	161	4202	2653	833863	43.17226
Dallas, TX	143	543	4202	3442	1255015	38.16341
Jacksonville, FL	93	452	1424	3277	845745	34.85965
Phoenix, AZ	118	635	3233	5506	1502139	33.70287
San Antonio, CA	72	663	2192	5901	1399725	32.03112
Charlotte, NC	59	230	1805	2999	837638	31.357
New York City, NY	335	1112	19170	31767	8396126	29.73821
Los Angeles, CA	251	764	7885	7624	3878725	23.38255
San Diego, CA	39	316	1456	3492	1349306	19.51531
Austin, TX	26	217	763	2117	859180	18.3223
San Jose, CA	38	270	1095	1812	992143	17.59187

Strengths and Limitations

Strengths: Model II utilizes a weighted system to emphasize the severity of crimes in a city, instead of only the number. As the severity of crimes can play a much greater part in how safe a city is, this model is a much more accurate scale of safety between cities than Model I.

Limitations: As with Model I, the estimated crime in My City for one year was calculated with a limited data set. Consequently, it may not be accurate to the actual values. Additionally, the weighted averages of the offense levels of each category of violent crimes was determined with a limited amount of statistical data.

Model III:

Assumptions

-If an arrest was not made, it was not necessary; no criminals escaped.
-The population was equal between all beats.

Procedure

Traditionally, crime rate only factors in the number of police-reported crimes occurred and does not include the seriousness or importance of the crime. In order to effectively compare the various beats in My City, it was necessary to take into account the number of crimes committed, the type of crime committed, and whether or not an arrest was made. We created a crime severity index that not only factors in the number of crimes that were committed, but also assigned appropriate weights to those crimes based on the FBI's Universal Crime Reporting system. This system involves the ranking of crime on a two tier scale, with Tier 1 being more severe. In addition, if an arrest was necessary, the crime was ranked more serious. In an Excel workbook, we parsed through the data and assigned the correct rank to the crime. If an arrest was made, additional weight was given. The data was then grouped by beat in order to facilitate the computation of the index sum per beat. For example, Beat 112 had an index sum of 140, suggesting that a several serious crimes were committed, while beat 1655 had a sum index of eight, suggesting that only a few less serious crimes were committed. In order to get the per capita crime severity index, it is necessary to divide the sum index by the population of each beat. However, because this data was not available, we assumed that the population of My City was spread equally throughout the beats. In beats with larger tourism industries, the crime can be significantly higher, however the population is small. As a result, the crime severity index can become slightly inflated. With this data and more time, our calculations would be slightly more accurate, factoring in other important aspects. As in most major cities, there is significant variation in crime rates throughout My City. While there is relatively little crime in the central section of the city, several other districts are extremely unsafe. This system allowed us to calculate that Beats 1533, 421, 612, 1121, 1834, and 624 had the highest six crime severity index ratings in My City. However, Beats 1655, 1652, 1613, 1621, 1651, and 2032 have the lowest crime severity index rating.

Minimum:	Maximum:
Beat 1655 0.00078286	Beat 1533 0.02094143
Note: Lower number equates to less crime	
Average:	0.00800393
Median:	0.00724143

Strengths and Limitations

Strengths: The model factors in type of crime based on FBI Uniform Crime Reporting and arrest necessity, and accounts for per capita differences rather than sheer number of crimes. Additionally, it allows effective comparison between various beats within My City.

Limitations: The model does not use actual beat population data, but assumes that population is spread evenly.

Conclusions:

Overall, these models effectively generated a safety rating for My City by comparing its Crime Severity Index to the Crime Severity Indices of well known American cities. After careful consideration of the various factors that affected the safety of a city, the main Crime Security Index was developed on the basis of a weighted violent crime rate. The initial model of developing a CSI based solely on violent crime rate valued all crimes equally, regardless of severity, while our second model addressed this concern. Our third model was more inwardly focused, analyzing the police beats within My City in order to determine which areas are in need of additional resources. This allowed us to create a basic plan for the improvement of the city, which became part of our letter to the mayor. Our models worked in tandem to create the most complete result, with our first, most basic model, leading directly into our second. Our second and third models combined to give a complete picture of My City's safety, both within and without.

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Letter to the Mayor:

Mayor of My City
123 CityLand Ave.
My City, NA 99999

Dear My City Mayor, November 11, 2015

Using sophisticated mathematical modeling and an intricate safety rating system, Team 5549 has concluded that My City's crime rate is quite high for its population. It is imperative to enhance the policing policies in order to promote the general welfare of citizens and improve the reputation of My City across the country. We have a simple proposal: increase the number of patrolling officers in certain beats where the crime severity index is high.

We designed two crime severity indices in order to effectively evaluate My City both internally and externally. Our first crime severity index is based on the number of times a crime was committed, base offense level for the crime (per the United States Sentencing Commission), and the average sentencing time associated with that level. Using this system, we were able to determine that My City has one of the worst crime problems of any large city in the United States. It ranked third from last in our data set, ahead of only Philadelphia and Indianapolis. While the crime rate of My City is unacceptable across the board, the largest issue is its homicide rate per 100,000 people, which is far higher than that of any other city. To make matters worse, the majority of these homicides did not result in arrests, which means that there may be hundreds of potentially dangerous criminals who still roam the streets freely.

As in most major cities, there is significant variation in crime rates throughout My City. While there is relatively little crime in the central section of the city, several other districts are extremely unsafe. In order to effectively compare the various beats in My City, we created an internal crime severity index in which we took into account the number of crimes committed, the type of crime committed, and whether or not an arrest was made. We ranked the seriousness of each crime according to the FBI Uniform Crime Reporting index. This system allowed us to calculate that Beats 1533, 421, 612, 1121, 1834, and 624 had the highest six crime severity index ratings in My City. However, Beats 1655, 1652, 1613, 1621, 1651, and 2032 have the lowest crime severity index rating.

The end result of this high crime rate is a general feeling of insecurity in the city, as well as a bad reputation in the worldwide community. If My City is to remain the hub of global commerce, finance, technology, and travel, sweeping policy changes will have to be made. First, current police resources should be allocated to the sections of the city that need them most, such as at the high-crime beats listed above. In addition, it may be possible to reduce police officers patrolling the sections of the city that have a relatively low amount of crime. These changes would lead to a lower overall crime rate, and the beginning of My City's renaissance as a respectable, safe member of the global community.

Sincerely,
COMAP Group 5549