

MCM 2019 Solution Paper**Problem Statement:**

Synthetic and non-synthetic opioids have presented a national crisis in the United States. Organizations such as the CDC, FBI and DEA are struggling to protect the health and lives from those in this epidemic and enforce existing laws surrounding this class of drugs. The spread of opioids has affected all cross-sections of the U.S population, which, in turn affects the quality of labor and life for many individuals. Most importantly, opioids are accounting for an increasingly large portion of overall drug reports, and, since some opiates (natural opioids) are prescribed by medical professionals, it can be hard to restrict their use and sale. In this report, we will attempt to analyze the proliferation of opioids in Kentucky, Ohio, Virginia, West Virginia, and Pennsylvania to better understand the so-called “Opioid Crisis,” and propose methods to eventually combat their abuse.

Assumptions and Justifications:

Throughout this report, we will mainly focus on the substances heroin, oxycodone, hydrocodone, tramadol, and fentanyl as well as fentanyl derivatives (from here on referred to as “fentanyl”), as they account for 85% of all opioid drug reports between 2010 and 2017. [2] Furthermore, many of the other opioids which make up the remaining 15% are inconsistent--they are absent in some counties or in some years, which makes them hard to account for.

At times we will group oxycodone and hydrocodone, as they have similar trends in usage, are chemically similar [2], and neither one makes up a substantial portion of the opioids being used in the four states by the year 2017.

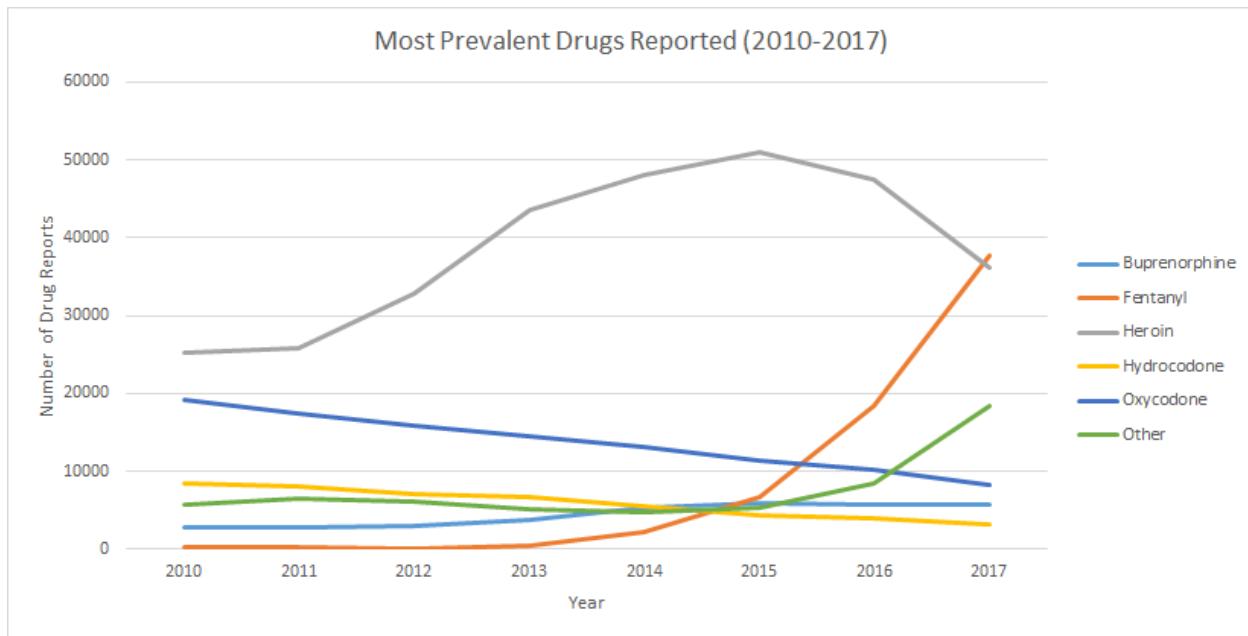
Part I:Modeling the Spread of Opioids:

Figure1: Depicts the total reports for the five top drugs between for 2010 - 2017

As implied by (Figure 1), the overall use of various opioids has undergone a dramatic realignment since 2010. Reports of oxycodone and hydrocodone have steadily decreased, and the rise of fentanyl has decreased the dominance of heroin--for better or worse. Heroin, hydrocodone, oxycodone, buprenorphine, and fentanyl make up nearly 90% of all opioid reports across the eight year period. In hopes of understanding the Opioid Crisis, we will first provide information about each of the major compounds which contribute to it.

Oxycodone

Oxycodone, sold under the brand name OxyContin®, is a primarily orally administered semi-synthetic opioid.[1] Oxycodone is very similar in structure to codeine, as is hydrocodone, another popular semi-synthetic opioid. Looking at the states of Ohio, Pennsylvania, West Virginia, Kentucky, and Virginia, counties that consistently had oxycodone as a high percent of their total drug charges were primarily focused around West Virginia and the respective state's border with West Virginia. Specifically, we believe the areas around Elliott County, Kentucky, Lawrence County, Ohio, Lawrence County, Pennsylvania, Giles County, Virginia, and Monongalia County, West Virginia act as epicenters for their respective states, as far as oxycodone go. We chose counties that had a high percentage of oxycodone usage compared to total drug reports, as opposed to using gross oxycodone reports per county, due to the fact that counties where oxycodone made up a significant portion of total drug charges were counties where oxycodone presented a serious problem.

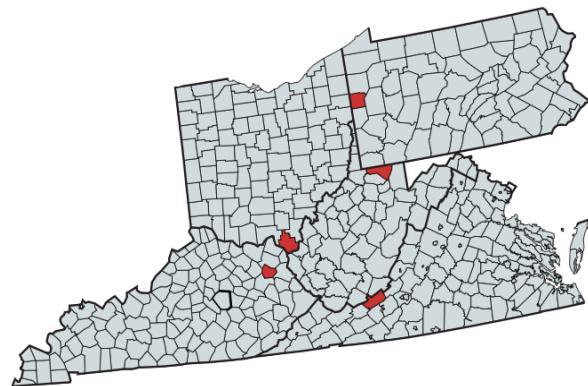


Figure 2: Illustrating “hotspots” for Oxycodone and Hydrocodone use for each state [6]

Geographically, areas hit hardest by oxycodone were the areas of eastern Kentucky and West Virginia, primarily occurring between the years 2012 - 2015.

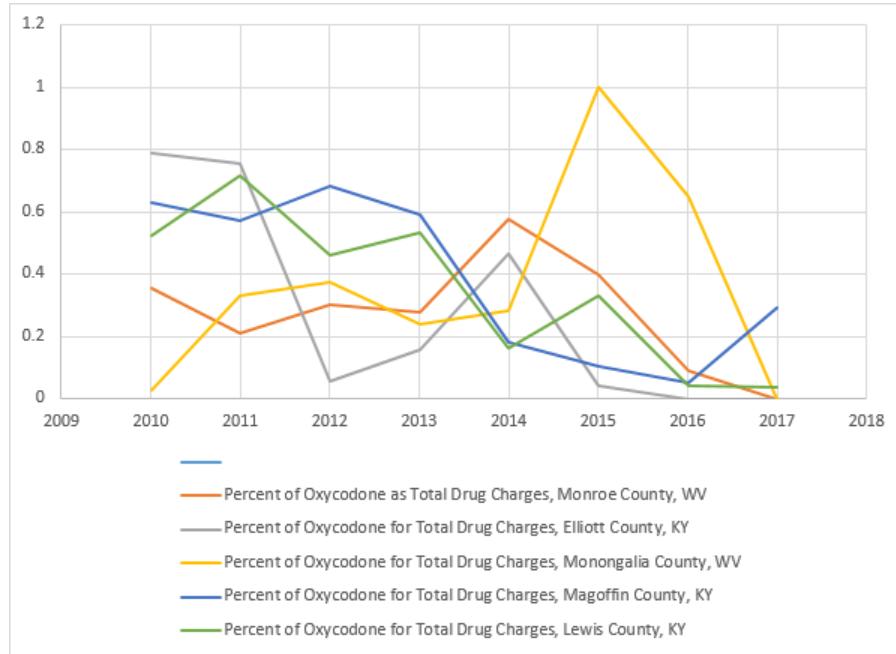


Figure 3: Percent of Oxycodone as part of the total drug charges for five counties in Kentucky and West Virginia

As seen in the above figure, the years 2015 - 2017 saw a substantial drop in the cases of Oxycodone reports in these five selected counties. This can be viewed as part of a larger trend, as shown in (Figure 1), where we see that Oxycodone reports are on a steady linear decline between the years 2010 - 2017 for all five of the states were are analyzing here. Thus making oxycodone and hydrocodone concerns, much ones which are on the decline.

While it was mostly these rural parts of the states that felt the largest hit by Oxycodone and Hydrocodone use, in proportion to the total drug reports for the counties, most cases of Oxycodone and Hydrocodone use occurred in major metropolitan areas such as Philadelphia, Columbus, and Pittsburgh.

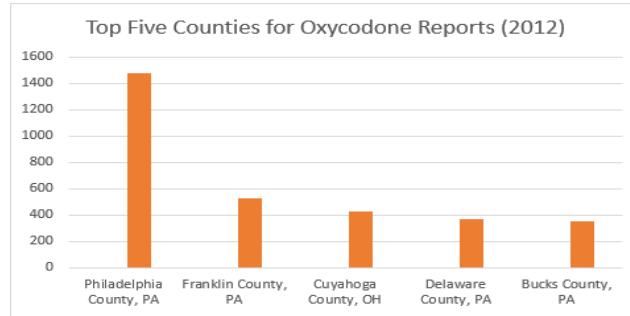
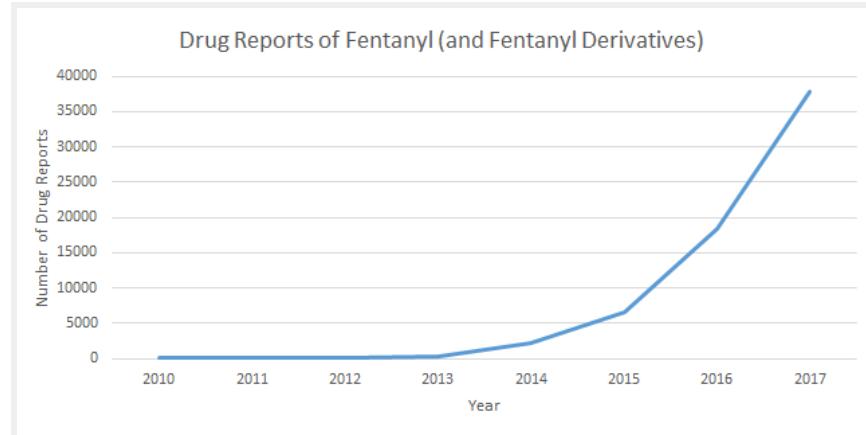


Figure 4: Top Five counties for Oxycodone Reports in 2012

Because these counties are home to major metropolitan centers, the large presence of oxycodone makes sense with everything covered thus far, as these cities act as major markets for the narcotic, while the hardest hit areas per capita remain the rural counties of eastern Kentucky and West Virginia.

Fentanyl

Based on the rapid increase in fentanyl reports between 2010 and 2017, the synthetic opioid fentanyl and its derivatives¹ [3][4] are a major cause for concern. Compared to other opioids, fentanyl is relatively new, with only 153 reports in 2012; however, by 2017, fentanyl accounted for nearly *half* of opioid reports and 15% of all drug reports across the five states. In fact, when combined with heroin, fentanyl accounts for nearly all of the upward trend of overall



¹ For the purpose of this report, “fentanyl and fentanyl Derivatives” [2] are considered to be: 3-Fluorofentanyl, 3-Methylfentanyl, 4-Fluoroisobutryl fentanyl, 4-Methylfentanyl, Acetyl fentanyl, Acryl fentanyl, ANPP, Benzylfentanyl, Butyryl fentanyl, Carfentanil, cis-3-methylfentanyl, Crotonyl fentanyl, Cyclopentyl fentanyl, Cyclopropyl fentanyl, Cyclopropyl/Crotonyl Fentanyl, Fentanyl, Fluorobutyryl fentanyl, Fluorofentanyl, Fluoroisobutryl fentanyl, Furanyl fentanyl, Furanyl/3-Furanyl fentanyl, Isobutyryl fentanyl, Methoxyacetyl fentanyl, o-Fluorofentanyl, p-Fluorobutyryl fentanyl, p-Fluorofentanyl, Phenyl fentanyl, p-methoxybutryl fentanyl, Remifentanil, Tetrahydrofuran fentanyl, trans-3-Methylfentanyl, U-47700, Valeryl fentanyl (33 different types used in the calculation of fentanyl report statistics)

opioid reports. Based on the current data, usage of fentanyl does not show signs of slowing in the near future.

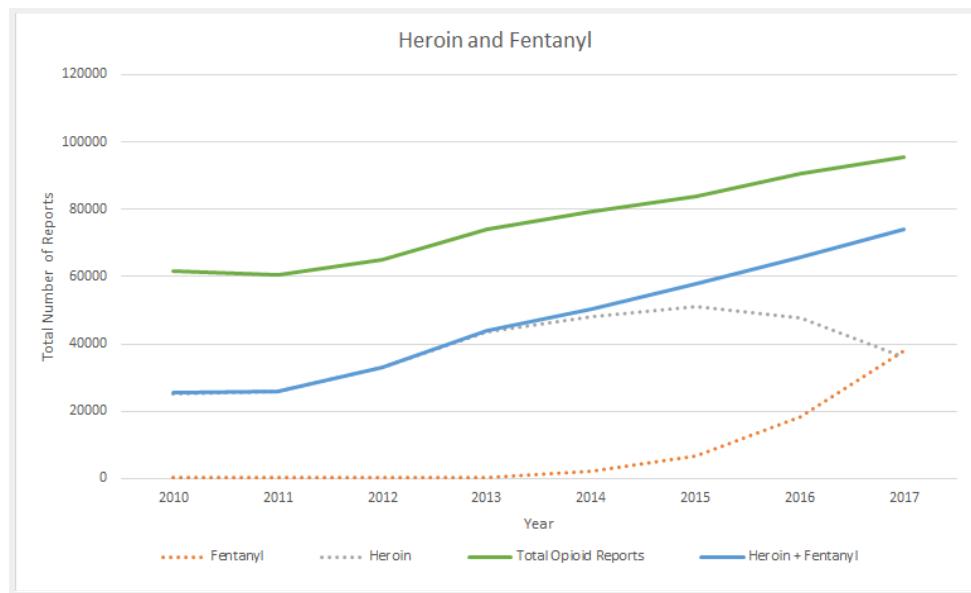


Figure 6: Illustrates Fentanyl and Heroin reports for the years 2010 - 2017

There is a clear concentration of fentanyl cases in population centers, as each of the five counties with the highest usage has a significant metropolitan area in it. In order of number of fentanyl reports: Cincinnati is in Hamilton County (OH), Cleveland is in Cuyahoga County (OH), Dayton is in Montgomery County (OH), Philadelphia, and Pittsburgh. Despite this, it is clear that fentanyl use is not only becoming an issue in densely populated areas, but it is also spreading outward from those areas. For example, in 2013, there were no counties in the 5-state area with over 100 reports for fentanyl or its derivatives, but by 2017, 65 of the 462 counties reporting (14.1%) had over 100 reports, and six of those had over 1000 reports.

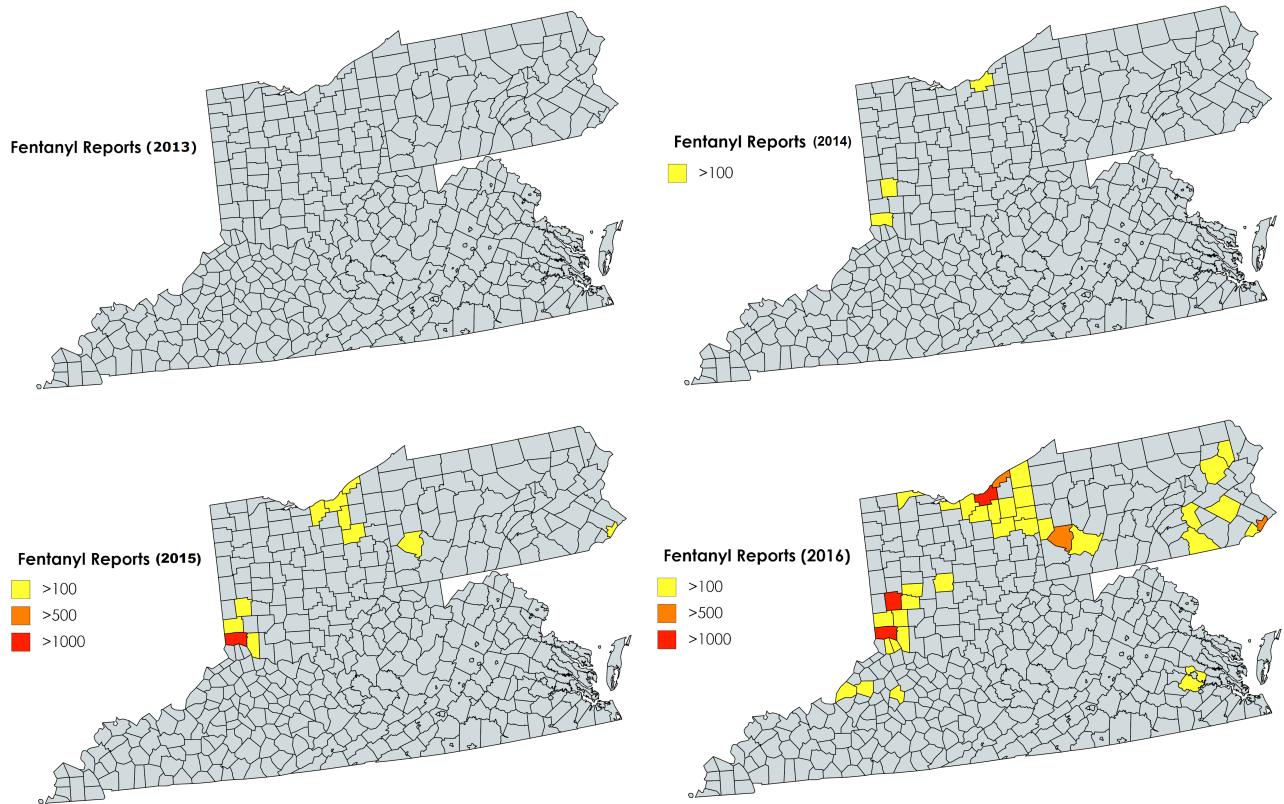
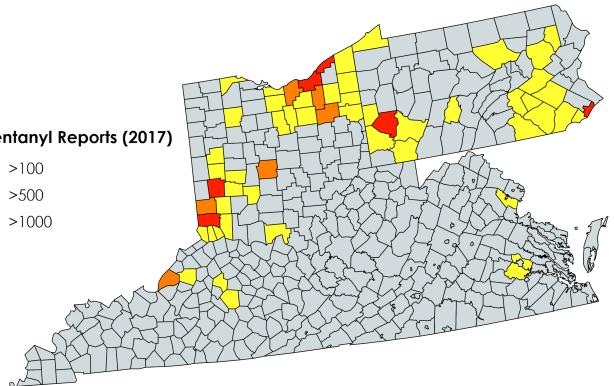


Figure 7: Showing the spread of fentanyl [6]

We can see from these graphics, that fentanyl first saw prevalence in Ohio, specifically in Cuyahoga, Montgomery, and Hamilton counties.

Within 5 years, fentanyl spread across nearly every state. Making fentanyl a major concern as far as the future spread and increase in opioid usage amongst these five states.



Tramadol

While the reports of tramadol usage are still small relative to the other major opioids, tramadol's positive trend and the fact that it is a new drug, having only been approved by the FDA in the 1990's, means that it might become problematic in the years past 2017. Like oxycodone, Tramadol is sold under a brand name, Ultram®. [5]

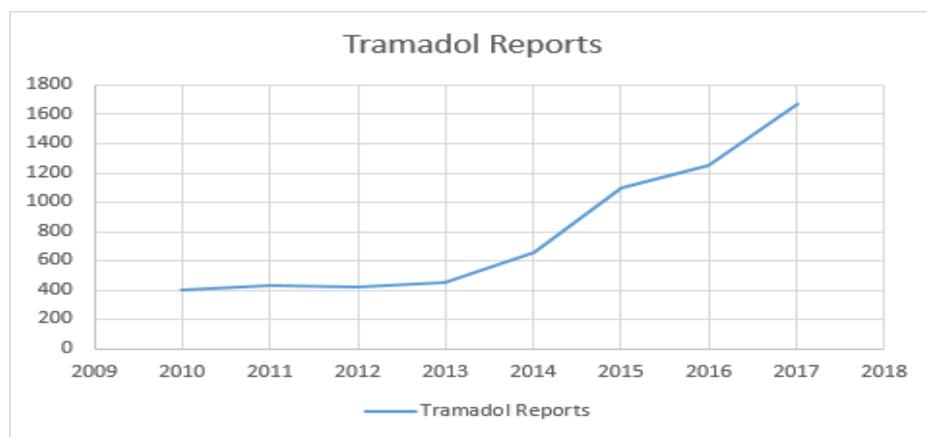


Figure 8: Illustrates Tramadol Report increases between 2010 and 2017

In the years 2010 to 2013, tramadol remained quite stable sitting at a total of 400 totals per year across the five states. Starting in 2013 and proceeding to 2017, we see a substantial linear increase in tramadol cases, reaching a peak in 2017 with 1668 cases between the five states. Assuming that these trends continue, it's possible that in the future tramadol might be competing with heroin or fentanyl. In fact, the increase in tramadol reports coincide with reports in fentanyl reports, as seen with (Figures 1 and 5). On a county-level we see this trend reflected, selecting Cuyahoga County, OH, Hamilton County, OH, and Philadelphia County, PA, we see that fentanyl and tramadol reports increase proportionally to each other.

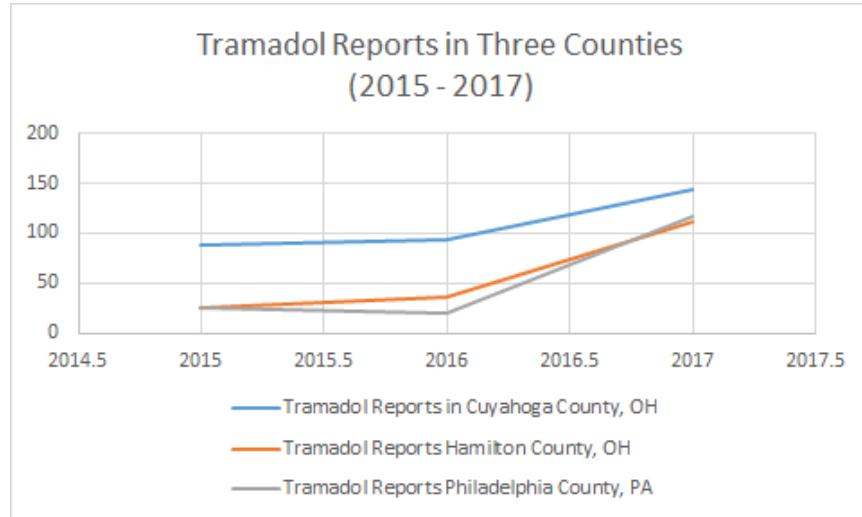


Figure 9: Tramadol reports for three metropolitan counties in Ohio and Pennsylvania

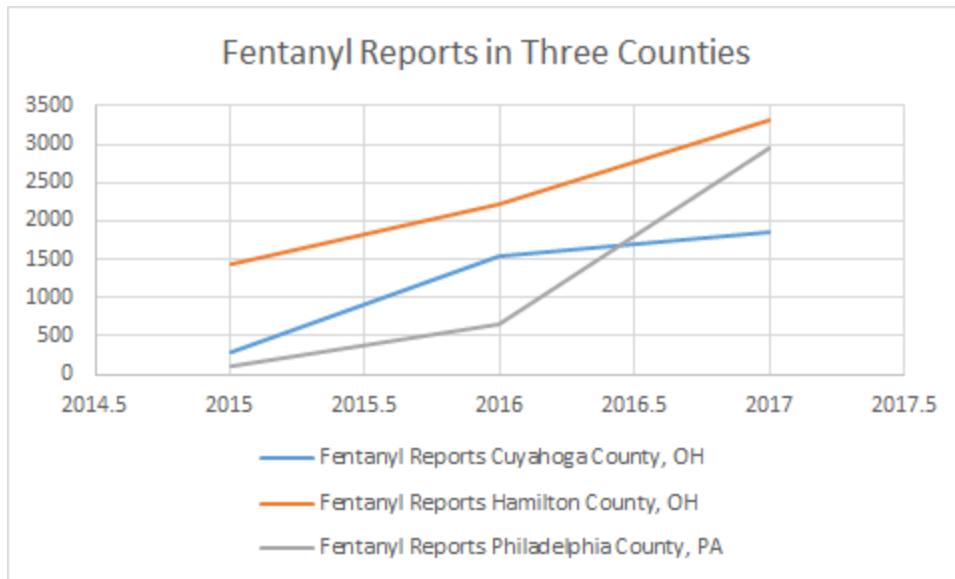
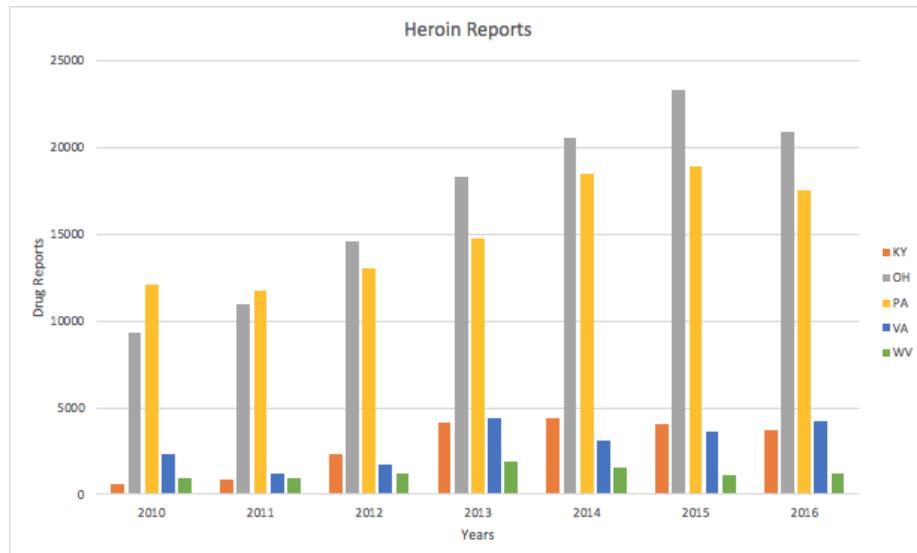


Figure 10: Fentanyl reports for three metropolitan counties in Ohio and Pennsylvania

With this in mind, it's possible that at some point tramadol might replace fentanyl as the dominant opioid just as fentanyl replaced heroin as the dominant opioid in these five states. The two are similar in the fact that fentanyl also started off extremely small and began seeing an increase just as heroin was increasing, this trend might continue with fentanyl and tramadol.

Heroin

Heroin is an opioid drug that is made from morphine. It can be extracted from the seed pod of various opium poppy plants. Heroin can be ingested through various way such as injections, snorting, smoking and orally. When examining the prevalence of heroin in the 5 states it was observed to be the most prevalent drug initially in many counties. When referring back to (Figure 1.) in the *Modeling the Spread of Opioids* section of the report it is shown that heroin was the more prevalent drug affecting these counties and making up the majority of the submitted drug reports. Starting in 2015 a decline came to the use of heroin and an increase in the use of fentanyl, however, it wasn't until near 2017 that fentanyl surpassed heroin in popularity, but heroin still made the vast majority of the reports. Of the total sum of drug reports for heroin the states OH and PA has the most significant number of reports indicating two major epicenters for the use of the drug.



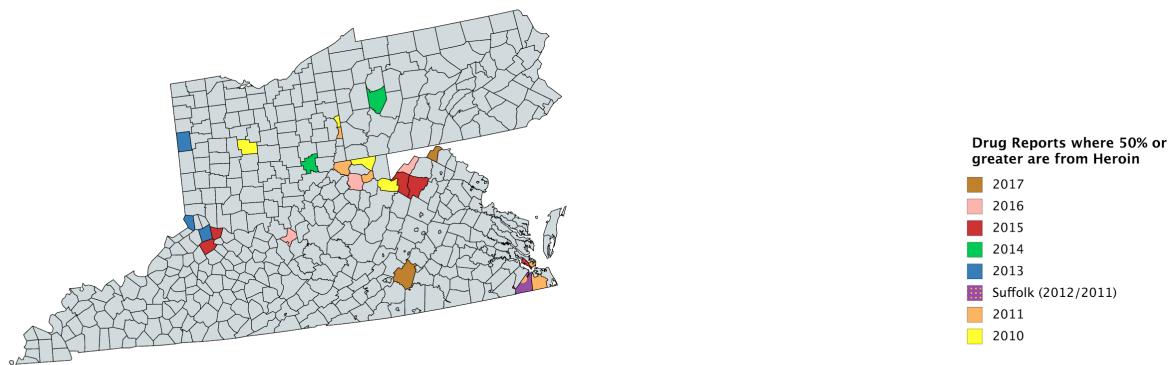
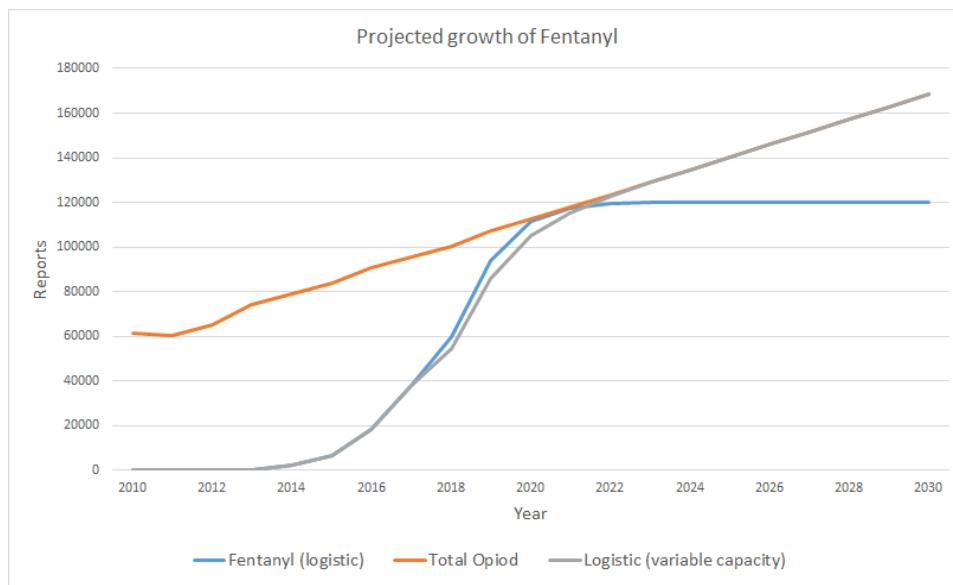
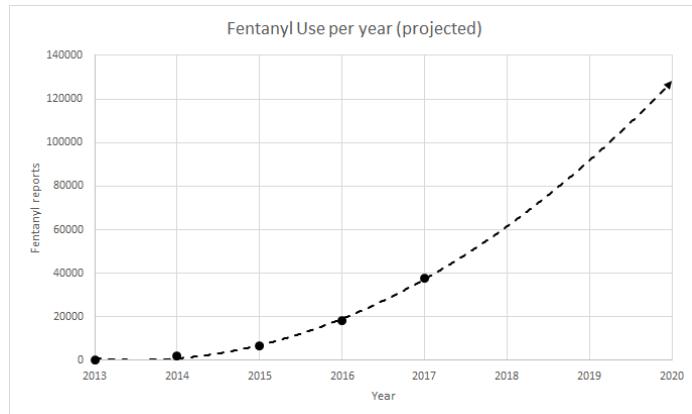


Figure 12: Counties where heroin reports made 50% or more of total drug reports [6]

It should be noted that some counties in (Figure 12) have large urban cities which would explain the large prevalence of heroin and those urban cities often make the majority of the reports. Rural counties with large amounts of heroin reports may be counties of interest for potential manufacturing and/or distribution sites for heroin. The figure does show some clustering and shifting of counties with a high amount of heroin reports. For example, both Boone and Pendleton Counties in KY had heroin reports over 50% in 2013, in 2015 the neighboring counties Bracken and Harrison had high percentages of heroin reports. We can observe this pattern shifting from county to county; this may provide some insight into the spread of the drug over the years between 2010-2017.

Model

As shown previously, fentanyl accounts for most of the overall growth in opioids in the years since 2013, so fentanyl will be a major component of our model. Since a relatively conservative quadratic model of the growth of fentanyl yields seemingly unrealistic numbers (over 50% of *all* drug use by 2020), we will add a logistic component, under the assumptions that: *total* opioid use among the five states provides a maximum for opioid use, and fentanyl cannot outpace total opioid growth. Here, fentanyl still



appears it will completely dominate opioid consumption, and become the only opioid used.

There are two logistic models presented in this graphic: the first

assumes a carrying capacity of 120000 (the highest observed total opioid reports), while the second allows for a variable carrying capacity based on a linear projection of total opioid use. This seems reasonable, considering that a drug's use depends on *users*, and the population of these 5 states should be growing over time.

These projections for the growth of fentanyl, and other opioids are somewhat unsatisfying. Oxycodone/hydrocodone and buprenorphine all have nearly linear decreases over the 8 year period, so it seems reasonable that these trends would continue in the near future. However, heroin, fentanyl, and tramadol have all seem sharp changes within the last 4 years, making it difficult to predict their future behavior. Heroin was dominant for many years, but saw a downward trend, beginning in 2015. While this trend seems like it will continue, with only two years of decline, it is very difficult to make a precise prediction about the *rate* of decline. Similarly, fentanyl and tramadol look like exponential growth if we look at all years 2010-2017, but the populations of these states can clearly not support that type of growth, even if this is projected until only 2020. With these factors combined, it has been very difficult to project the overall trends in opioids.

Additionally, when comparing these extreme trends in synthetic opioids to the more stable demographic and socio-economic factors provided for the various counties, it has been challenging to find predictive patterns. Any correlations between variables seems like they can mostly be explained by differences between the populations of the counties.

Part II:

Analyzing the socio-economic data we received from Census demographics, we see that there are strong correlations between education, retirement aged population, number of people without high school diploma with opioid drug reports. Along with those strong correlations, we saw correlations between children's guardians who are grandparents, number of people with bachelor's degree or higher with opioid reports.

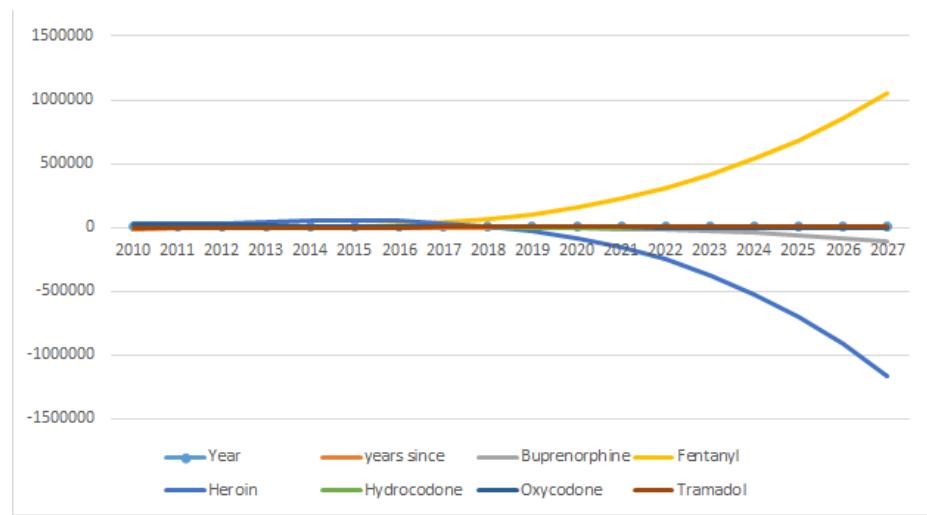
From this data, we believe the frequent users of opioids are the elderly, new parents, and people out a bachelor's degree. Unfortunately, this means that the people most at risk for opioid abuse are likely those who are already at a disadvantage--economically or health-wise. Furthermore, since we saw a strong relationship between "Householder living alone (65 years and over)", "Number of women 15 to 50 years old who had a birth in the past 12 months", and the rise of synthetic opioids such as fentanyl, those without a strong support system (possibly people without family or friends cohabiting with them or any kind of community support) are even more likely to fall victim to opioid abuse. Interestingly enough, these populations are those who reasonably have the most contact with medical personal. Another hypothesis for the spread of opioids is that these populations are falling victim to over-prescribing by medical personnel. So based on our model, we believe counties with high populations of people 65 and older, and counties with a high population of new parents should have higher rates of opioid usage.

The strong correlation between people without high school diplomas or equivalency and opioid usage, is one that might be rooted in the fact that this population consists of a reliably low-income portion of the total population. Based on this data, our hypothesis is that one's income level decimates the probability of one using opioids. Hence counties with a low median household income should have higher reports of opioid usage.

Part III:

Unfortunately, many of the variables that appeared to be strong indicators of opioid use are widespread demographics, which would mean a possible strategy to counter the opioid crisis would need to be a very large-scale effort.

However, one pattern we observed that could be used to simplify this process is that most of the opioids are already on the decline. Based on our projections, fentanyl will account for



nearly all of the opioid use within the next few years. This means that our strategy will focus mostly on combating the rise of fentanyl, tramadol, and other synthetic opioids that could fill the vacancies left by heroin, oxycodone, and hydrocodone.

As stated in Part II, these types of synthetic opioids have positive correlations with elderly homeowners living alone, women ages 15 to 50 who gave birth in the last 12 months, and high school dropouts, which leads us to believe that opioids are a symptom of a larger economic trend. With this in mind, our proposed solution is for these 5 states to invest more heavily in educational support programs, support for new parents, and greater regulation (and more responsible oversight) of prescription medication for the elderly. This could mean check-in services on the elderly, the creation of more community college or GED programs in these areas, and possibly the creation or expansion of regulations on prescriptions. Paired with a general

increase in funding for K - 12 education and economic support for low-income individuals these might solve the problem of the opioid epidemic in these five states.

Lastly, based on our conjecture regarding healthcare professionals, we feel our model could benefit from further data regarding disability status (which was omitted from some of the socio-economic county data sheets), and based on our inverse relationship between opioid use and economic status, we could make a better model with income information--or even the "internet usage" numbers, which were also omitted.

References:

Drug information:

- [1] <https://americanaddictioncenters.org/oxycontin-treatment/vs-oxycodone>
- [2] <https://www.drugabuse.gov/>
- [3] https://www.nflis.deadiversion.usdoj.gov/DesktopModules/ReportDownloads/Reports/11350_R1_NFLIS_Research_Brief_Fentanyl.pdf
- [4] <https://ndews.umd.edu/sites/ndews.umd.edu/files/fentanyl-remains-most-significant-synthetic-opioid-threat-2018.pdf>
- [5] http://www.if-pan.krakow.pl/pjp/pdf/2009/6_978.pdf

US States and Counties

- [6] <https://mapchart.net/usa-counties.html>