PREVIEW PAPER: EXCELLENT

The summary for this paper was considered good. The paper made use of a logistic growth model for question one, but the carrying capacity was not clearly defined or discussed. Additionally, the role of religious values and health limitations was not clearly defined or adequately justified. For question two, the linear combinations used in the model made use of weights that were not justified. For question 3, the use of financial costs is an interesting approach, but it is assumed that the costs of crimes is identical for each drug. On the whole, the lack of captions and references for tables is problematic, but the paper does include citations in other places. Finally, the random variables were not clearly described, and it was not clear how the simulations related to the approach employed. On the plus side, the team laid out clear and insightful assumptions with good justifications

Too Cuul to Juul

Executive Summary:

To smoke or not to smoke? That is no longer the question. No more is the general public ignorant of the dangers of substance abuse and addiction. Due to the rising epidemic of electronic cigarettes, more and more teens have been introduced to a lifestyle of addiction and found gateway into more harmful drugs. The populations affected by this spread of substance abuse are increasing in size; friends, family, and partners of those addicted are affected in significant ways as well. In this paper, we created various mathematical models to evaluate the spread and effects of substance abuse in the United States.

In Part 1, we constructed a model that would project the spread of nicotine use due to vaping in a new generation over the next ten years. We used a logistic growth regression model based on data from 2011 to 2015 to extrapolate our data and show how nicotine spreads. The model showed us that after 2015, the spread of vaping began to level off, and by 2029, it had almost reached the carrying capacity of 74.298% of high schoolers. We compared this to a model of cigarette growth based on data from 1968 to 1974, represented by a quadratic regression. These two models were represented well by their respective regression lines. This shows us how cigarettes and vaping spread differently.

In Part 2, our mathematical model was intended to determine how likely an individual was to be addicted to nicotine, marijuana, alcohol, or un-prescribed opioids. In order to do this, we assigned certain characteristics —specifically gender, income level, the presence of mental disorders, and the popularity of the drug— values, which were added together in order to form an index number. We titled this index number "Substance Index." If the index number achieved the threshold of 55, the individual in question was prone to using that type of drug. Using the JavaScript coding language, we randomly assigned the four characteristics in a for-loop. We then simulated a class of 300 high school seniors with these randomly assigned characteristics by iterating the loop 300 times, producing an index score for each "student." Then, the program was run five times, and we took the average for each substance in order to find the profile of addiction of a class of 300 seniors in high school. This showed us that alcohol would be used the most, followed by marijuana, nicotine, and opioids, while 122.6 students did not reach the index threshold at all.

In Part 3, we constructed a robust metric in order to determine which of the four substances from Part 2 has the most substantial impact on the US population. In order to determine this, we split our categories into financial and non-financial impacts. Financial impact was composed of cost of purchasing and cost of enforcing, while non-financial impact was composed of number of related deaths and number of related arrests based on drug abuse. In combining this data within their respective categories, we found opiates to be the most impactful financially followed by nicotine, alcohol, and marijuana. In the non-financial category, alcohol

was the most impactful in regards to deaths and crimes related to it, followed by opiates, marijuana, and lastly, nicotine.

Using mathematical models to predict the rise in the spread of e-cigarette usage in America's new generation of smokers and measure the propensity for high school seniors to use commonly abused drugs. These measures give us the ability to rank the harmful effects of these drugs and educate the new population of addicts on the future they could place themselves in. This is currently a subject that many are aware of, but are not educated on the dangers and effects. We hope that these analyses can shed light on this ill-covered issue.

Sincerely, Team #12313

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Part 1: Darth Vaper

Restatement of the Problem

Vaping, a significant source of nicotine, is spreading in popularity. We must build a model that shows how nicotine use due to vaping will spread over the next ten years. Then, we must compare how vape usage diffuses to how cigarette usage diffused in the past.

Assumptions and Justifications

1. **Assumption:** One use of a vape constitutes a user.
    a. **Justification:** Most data conveys how many people have vaped at least once. Making this assumption allows us to use a conservative approach and qualify any uses of an e-cigarette as the spread of an epidemic. Rather than setting a standard of a higher number of uses, we assume a single use characterizes a demographic that has been influenced nicotine.
2. **Assumption:** Nicotine use due to vaping in high school students is indicative of the whole population.

   a. **Justification:** Most data polls only high school students. Also, high school student are the demographic with the highest proportion of vape usage, and this allows us to have a worst-case scenario for a more conservative approach. "Compared with adults aged 25 and older, young adults are more likely to try e-cigarettes and report having used e-cigarettes in the past 30 days"[1].
3. **Assumption:** We assume logistic growth in vaping has a carrying capacity of 74.298% of the population.
   a. **Justification:** Our logistic growth equation yields a carrying capacity of 74.298% of US high school students. It is unreasonable to assume that 100% of the population would eventually vape, because a portion of the population is held back by religious values or health limitations.
4. **Assumption:** Nicotine usage in the United States is indicative of nicotine usage worldwide.
   a. **Justification:** It is easier to gather data for one country than to gather data globally. Therefore we chose the United States as our country for data compilation because it has the most accessible data and is wealthy enough for the majority of its residents to have access to and funds for electronic nicotine devices.
5. **Assumption:** All methods of electronic nicotine consumption i.e. e-cigarettes, e-pipes, e-cigars, juuls etc. can be generalized by vape usage.
   a. **Justification:** Generalizing all e-smoking devices as vapes allows us to compile cohesive data on electronic nicotine usage.
6. **Assumption:** High school students include only students aged 15-18.
   a. **Justification:** Most freshmen begin high school the year they turn 15 and and graduate the time they turn 18. This assumption makes it safe characterize certain age demographics as high school students and collect data in that way.
7. **Assumption:** The year 2011 is t=0.
   a. **Justification:** Because our data began in the year 2011, the base year, or year 0, on our graph is 2011.
8. **Assumption:** In the cigarette study by the National Institute of Health, the distribution of those surveyed was split evenly male and female.
   a. **Justification:** In order to combine the two proportions of male and female smokers without direct counts, the two sample sizes must be equal. Therefore this assumption is necessary in order to compare the smoker distribution to the electronic smoker distribution.
9. **Assumption:** In the cigarette study by the National Institute of Health, the distribution of those surveyed that were 15-16 and 17-18 were equal.
   a. **Justification:** In order to combine the two proportions of 15-16 and 17-18 year old smokers without direct counts, the two sample sizes must be equal. Therefore

this assumption is necessary in order to compare the smoker distribution to the electronic smoker distribution.

10. **Assumption:** Cigarettes rose in popularity around the time of 1968 to 1974.
    a. **Justification:** We have evidence that suggests cigarettes were popular in this time period and have data to back the change in the percentage of users. Therefore we must assume that the rise of cigarette usage in this time period is comparable to the rise in percentage of users of e-cigarettes in the time period of 2011-2029.
11. **Assumption:** Cigarette usage used to be increasing but is currently declining.
    a. **Justification:** As a result of studies showing the effect of time in the popularity of cigarettes, we can say that cigarettes popularity increased in the 1960's and 1970's and decreased in the years following. "Current smoking has declined from 20.9% (nearly 21 of every 100 adults) in 2005 to 14.0% (14 of every 100 adults) in 2017"[3].
12. **Assumption:** Cigarette usage can best be modeled by a quadratic regression line.
    a. **Justification**: The coefficient of determination for the quadratic regression of our cigarette data, or r^2, is .780, which shows a moderately strong estimation, making a quadratic regression the best.

Analysis of the Problem

This problem requires a prediction of the spread of nicotine usage due to vaping. To do this, we must collect data from past years and use it to predict diffusion. Using high school students as our population, we must determine what percentage of high school students have vaped and use this to predict usage over the next ten years. Because of the way nicotine consumption due to vaping is spreading, a logistic regression model is the best way to show this spread. Lastly, we must make a similar model for the spread of cigarette use in order to compare the spread of vaping to the spread of cigarettes.

Developing the Model

First, we gathered data of the percentage of high school students in 2011 to 2015 that have vaped at least once [2].

Table 1:

Percent of High School E-cigarette Users Since 2011	
Years Since 2011	**Percent of Users**
2011	4.7
2012	10
2013	11.9
2014	27.3
2015	37.7

The equation for logistic growth is:

$$y = \frac{L}{1 + Ce^{-Lkt}}$$

This equation uses the following variables and constants:

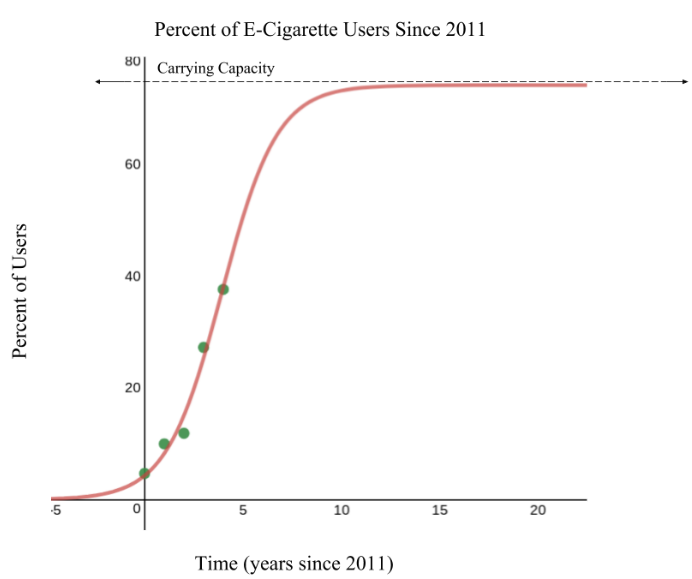
1. L = The Carrying Capacity, or maximum possible percentage of high school students using vape products
2. C = The Constant of Integration
3. k = The Constant of Proportionality, or the rate at which the percentage of high school students using vapes is increasing
4. t = Time in years since 2011
5. y = Percent of US high school students using vape products

Using stat plots and regression programs, we next created the following logistic regression model with our data

$$y = \frac{74.298}{1 + 16.241e^{-.710t}}$$

where t = 0 represents the year 2011, and our carrying capacity for vape usage is 74.298%.

Graph 1:



This equation allows us to extrapolate the data and predict the spread of nicotine use due to vaping in the future. Currently in 2019, according to this model 70.403% of high school students have vaped at least once. Looking forward in the next ten years, 74.295% of high schoolers in 2029 are projected to have vaped at least once based on our equation.

Next, we had to gather and combine data on cigarette consumption from when cigarettes were rising in popularity [4].

TABLE 4.—Estimates of the percentage of current, regular cigarette smokers, teenagers, aged 12 to 18, United States, 1968—1974

Year	Ages 12-14		Ages 15-16		Ages 17-18		Ages 12-18	
	Male	Female	Male	Female	Male	Female	Male	Female
1968	2.9	0.6	17.0	9.6	30.2	18.6	14.7	8.4
1970	5.7	3.0	19.5	14.4	37.3	22.8	18.5	11.9
1972	4.6	2.8	17.8	16.3	30.2	25.3	15.7	13.3
1974	4.2	4.9	18.1	20.2	31.0	25.9	15.8	15.3

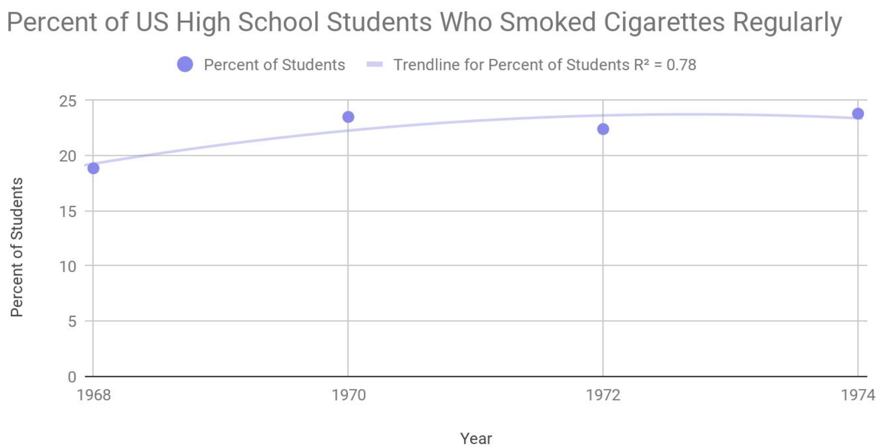
NOTE: Current regular smoker includes respondent who smokes cigarettes at least weekly.
SOURCE: National Clearinghouse for Smoking and Health (*61,63,65*).

In order to condense the above data into a total percentage which we could use to draw comparisons with modern vape use percentages, we averaged the four values of Age 15-16 Male, Age 15-16 Female, Age 17-18 Male, and Age 17-18 Female. Because of our assumption that Male and Female populations were equal, and that 15-16 and 17-18 populations were equal, we were able to average the four to find the compiled percentage.

Table 2:

Percent of US High School Students Who Smoked Cigarettes Regularly	
Year	**Percent of Students**
1968	18.85
1970	23.5
1972	22.4
1974	23.8

Using stats plots and regression models, we created another regression model for the spread of cigarettes. Since cigarette usage is declining, we used a quadratic regression model to find the best fit, which shows how cigarette usage began to decline.



Graph 2:
The trendline follows a quadratic pattern: $y = (-0.203)t^2 + 801.406t - 790440.238$
y = Percent of US High School Students Who Smoked Cigarettes Regularly
t= time in years

Using stats plots and regression models, we created another regression model for the spread of cigarettes. Since cigarette usage is declining, we used a quadratic regression model to find the best fit, which shows how cigarette usage began to decline.

Results and Analysis of the Model

The results produced by this model were reasonable and well-supported given our assumptions. Our assumption that high school students in the United States could represent nicotine use due to vaping worldwide allowed us to narrow our focus on a specific set of data. This set of data worked best because high school students in the U.S. have the best access to vapes, giving our model a conservative approach. A conservative approach is best for this problem because a worst-case scenario will allow for an adequately extreme response to the vaping epidemic.

Based on our logistic regression model, the following percentages were predicted:

Table 3:

Projected E-Cigarette Growth	
Year	**Predicted Precent of Users**
2011	4.309
2012	8.269
2013	15.084
2014	25.357
2015	38.123
2016	50.682
2017	60.453
2018	66.78
2019	70.403
2020	72.331
2021	73.318
2022	73.813
2023	74.059
2024	74.181
2025	74.24
2026	74.27
2027	74.284
2028	74.292
2029	74.295

These percentages are reasonable given our assumptions and what we have personally experienced as high school students. The results show how the percentage of vape users start from 4.309 percent and increase in a logistic fashion, approaching the carrying capacity asymptote of 74.298 by 2029. If we divide the carrying capacity by two, we can determine that vape usage is spreading the fastest when the percent of users is 37.149%, which is likely around 2015 based on the data in Table 2. This tells us that after 2015, the spread of vaping begins to level off.

The last part of our problem is to compare our model to the spread of cigarette usage. Vaping is increasing in popularity, just as cigarettes once were. However, vaping is increasing at a much more dramatic rate, helped along by advancements in communications technology. In our model, we can also see the beginning of the decline of cigarette usage; this trend continues as seen in present day [3]. The decline of cigarettes is helped along by the growth of public awareness of its harmful effects, whereas vapes are often seen as less harmful or not harmful at all [29].

Lastly, different mathematical regressions were used to model both. We used logistic growth to model the spread of vaping, while we used a quadratic equation to model the spread of cigarettes. This shows how the two different mediums of nicotine consumption diffuse in different ways.

Strengths of the Model

The logistic model was a good fit for this situation. The spread of nicotine use due to vaping is growing in a seemingly exponential fashion, but we know that the growth must level off as it nears the carrying capacity, making a logistic model most reasonable. The points of data that we gathered fall closely along our regression line, as seen in Graph 1. This shows that our model is a close fit for the data trend.

The quadratic model for the cigarette data was also a decent fit for our model. The r^2 value is .780, showing a moderately strong relationship, as seen in Graph 2. This coefficient of determination shows that our equation of best fit can adequately be used to project future growth past our data set.

Weaknesses of the Model

Our model relies on a very select amount of data and projects far into the future. Therefore our extrapolations may not be as accurate as they could be if we had a larger data set. The carrying capacity of the model also provides complications as it is based on our model rather than data appropriate to the future extrapolations. Because our data does not have a percentage higher than 37.7 and does not go past the year 2015, the carrying capacity is may not accurately represent the actual data. Our assumptions also complicate our solution as we had to combine two data sets for the cigarette users in the 1968-1974 time period. These assumptions state that the proportions of males and females are equal, and that the proportions of youth between 15-16 and 17-18 are equal, whereas there may be discrepancies. This can cause a proportion of youth to be misrepresented and our values to be incorrect.

In conclusion, although we used a small amount of data to make inferences over a long time period, our model is a good fit for the situation and for the data we *do* have.

Part 2: Above or Under the Influence?

Restatement of the Problem

Addiction and abuse of substances is often caused by both internal and external and social factors. We must develop a model that will predict a high school student's likeliness to get addicted to a substance based on different characteristics and demographics. We must take into account the properties of the different substances and the outside social influences that will influence a student's likelihood to get addicted to a substance. Then, we must use the model to predict how many students in a hypothetical class of 300 seniors will be likely to get addicted to the following substances: nicotine, marijuana, alcohol, and un-prescribed opioids.

Assumptions and Justifications

1. **Assumption:** The whole population is indicative of high school seniors.
    a. **Justification:** Finding data on high school seniors who are underage for alcohol and nicotine products is difficult due to all activities being illegal. Therefore, we compiled data of the population as a whole to gather more comprehensive data.
2. **Assumption:** All incomes are classified as either high income or low income; there is no middle class.
    a. **Justification:** The data found classifies income in the bottom and top quartiles, therefore eliminating the variable of the middle class in the influence on drug use simplifies the problem and allows us to gather data on the more extreme income discrepancies.
3. **Assumption:** There is no relationship between low income, mental disorders, and gender.
    a. **Justification:** In order to establish an index model, the variables must all be independent from one another. It is safe to assume low income, mental disorders and gender do not affect one another. Therefore the index model is applicable.
4. **Assumption:** The only source of nicotine is cigarettes.
    a. **Justification:** The most common medium of nicotine consumption can be classified as smoking. This helps simplify our data to create our index model because there is more data readily available on cigarettes than other less popular and accessible methods of using nicotine products.
5. **Assumption:** An individual's likelihood to use a certain drug is determined entirely by their gender, their income level, whether or not they possess a mental disorder, and the popularity of the drug.
    a. **Justification:** These four characteristics provide a sufficient look at what affects likelihood without being becoming overly complicated and difficult to manage. These four have a significant enough effect on drug usage to justify using them as our only variables.
6. **Assumption**: The drugs that are used by a higher percentage of high school students have a higher likelihood of being addictive substances.
    a. **Justification**: The higher the percentage of high school students that use a substance is, the higher the popularity of the drug is. A higher popularity results in a higher availability and a higher likelihood of peer pressure, making the drug more likely to be used.
7. **Assumption**: Higher incomes are more likely to use alcohol or marijuana than lower incomes. Lower incomes are more likely to use nicotine or opioids than higher incomes.
    a. **Justification**: A higher percentage of upper income brackets use alcohol and marijuana than lower income brackets. A higher percentage of lower income brackets use nicotine and opioids than higher income brackets [5].

8. **Assumption:** For every one teen who experiences a mental health disorder, there are four teens who do not.
    a. **Justification:** "Approximately 1 in 5 youth aged 13–18 (21.4%) experiences a severe mental disorder at some point during their life" [6].
9. **Assumption**: Students in the sample of 300 high school seniors are capable of using more than one of four substances.
    a. **Justification**: Usages of the four different substances are not mutually exclusive.
10. **Assumption:** Students who have used the less popular and higher level drugs have used the more popular drugs.
    a. **Justification:** The more common drugs are easily accessible and more popular therefore act as a gateway to the more hardcore drugs. Once the users become used to the effects of one drug, they move on to the drugs with harsher effects. Therefore it is safe to assume that if a person uses a less popular drug, they have previously used the more popular ones. For example an opioid user has likely drank alcohol or smoked a cigarette.

Analysis of the Problem

This problem requires some sort of method of measurement of an individual's likelihood of abusing a specific substance. This likelihood should be based off of a collection of characteristics of both an individual and the drug itself. The easiest way to measure an individual's likelihood would be to create an index that assigns specific values to specific characteristics. These values could be added together to find an individual's index number.

Then, this model must be applied to a sample of 300 high school seniors. The four substances given are nicotine, marijuana, alcohol, and un-prescribed opioids. The best way to do this would be to use a program using the JavaScript coding language to randomly assign the four characteristics in a for-loop. By making the loop iterate 300 times, the program simulates a class of 300 high school seniors with each student having a random set of characteristics. Then, the program was run several times, and we took the average for each substance.

Developing the Model

To develop our index, we decided upon four different determining characteristics: gender, income level, the presence or absence of a mental disorder, and the popularity of the drug. Further research showed us how much of an effect each characteristic has on an individual.

No matter the substance, males have a higher likelihood of substance use than females, so we assigned the male gender a 10 and the female gender a 5 [7],[8].

Research also showed us that the presence of a mental disorder can also increase in individual's likelihood, so we assigned a 10 to the presence of a mental disorder and a 0 to the absence of a mental disorder [9].

Based on the data below, we assigned numbers to each substance according to popularity, since a higher popularity leads to a higher availability and more pressure to use that specific substance [10].

Table 4:

Percent of US High School Seniors Who Have Used Various Drugs in their Lifetime (2018)			
Nicotine(Cigarettes)	Marijuana	Alcohol	Un-Prescribed Opiods
23.8	43.6	58.5	15.5

[10]

We assigned a 30 to alcohol, a 25 to marijuana, a 20 to nicotine, and a 15 to opioids.

In terms of income level, different substances are affected differently. Because of this, we assigned different income-based numbers to different substances, determined by how that specific drug is affected by income [11]. If alcohol or marijuana is the substance in question, lower income was assigned a 10 and higher income was assigned a 20. If nicotine or an opioid is the substance in question, lower income was assigned a 20 and higher income was assigned a 10 [12].

To get our index number, all of these variables are added together to get this equation:

$$SI = G + I + M + P$$

with the following variables:

1. SI= substance index number
2. G= gender variable
3. I= income level variable
4. M= presence or absence of a mental disorder
5. P= popularity level of the substance

Table 5:

Given Substance: Alcohol		Contribution to Index
Female (+5)	Male (+10)	
Upper Income Quartile (+20)	Lower Income Quartile (+10)	
No mental disorder (+0)	Mental Disorder (+10)	
	Popularity factor (+30)	
	Index:	

Given Substance: Nicotine		Contribution to Index
Female (+5)	Male (+10)	
Upper Income Quartile (+10)	Lower Income Quartile (+20)	
No mental disorder (+0)	Mental Disorder (+10)	
	Popularity factor (+20)	
	Index:	

Given Substance: Marijuana		Contribution to Index
Female (+5)	Male (+10)	
Upper Income Quartile (+20)	Lower Income Quartile (+10)	
No mental disorder (+0)	Mental Disorder (+10)	
	Popularity factor (+25)	
	Index:	

Given Substance Opiod:		Contribution to Index
Female (+5)	Male (+10)	
Upper Income Quartile (+10)	Lower Income Quartile (+20)	
No mental disorder (+0)	Mental Disorder (+10)	
	Popularity factor (+15)	
	Index:	

Once this index number is found, we measured it against a set threshold of SI=55. If an index number exceeds this threshold, then that individual is prone to use the substance in question.

Using this model, an individual who is an upper income male with a mental disorder would have the following substance index number if alcohol is the given substance:

$$SI = 10 + 20 + 10 + 30$$

$$SI = 70$$

Since this individual's substance index number is greater than 55, he is prone to alcohol substance abuse.

Next, we needed to predict how many students among a class of 300 high school seniors with varying characteristics would use the four substances. We used the code language JavaScript in App Lab on Code.org to create a program which simulated the drug use of a class of 300 high school seniors. We used a series of variables to store random values to represent each characteristic for a given student. We used a series of if-statements to test for each characteristic and added the respective amount to the substance index for the given student. After each if-statement had been tested, a final set of if-statements tested whether or not the sample student was prone to use Alcohol, Marijuana, Nicotine, or Un-prescribed Opioids. We then used a for-loop to repeat the program 300 times. Finally, we ran the program five times and recorded the number of students who used each substance in each set of 300. This allowed us to apply our Substance Index to 300 students, five times over.

Our code is displayed in full in the appendix.

Analysis and Results of the Model

This model produces comprehensive data that gives a sufficient view of the hypothetical situation. Based on our assumptions, our results are reasonable and well-supported. Our assumptions were necessary in order to simplify our data set and in order to allow us to use the data as we did.

The results of running our program five times are displayed in the table below:

Table 6:

	Number of High School Seniors Out of 300 Who Would Use a Given Substance				
Drug Type	**Alcohol**	**Marijuana**	**Nicotine**	**Opioids**	**No Substances Used**
Trial 1	180	98	30	14	120
Trial 2	165	102	24	8	135
Trial 3	176	111	24	15	124
Trial 4	181	120	28	16	119
Trial 5	185	114	35	17	115
Average	**177.4**	**109**	**28.2**	**14**	**122.6**

These results show how five different random samples of 300 high school seniors would likely use the four given substances, based on applying our Substance Index model to each randomly-found individual. Our data is supported by Table 2, which shows how alcohol is the most highly used substance, followed by marijuana, then nicotine, and lastly opioids as the least used substance. An average of 177.4 seniors consumed alcohol; an average of 109 seniors used marijuana; an average of 28.2 seniors used nicotine; an average of 14 seniors used opioids; and an average of 122.6 did not reach the threshold and did not use a substance.

Strengths of the Model

Our index does a decent job of taking several different characteristics into consideration and giving comprehensive results of an individual's propensity for using a certain drug. The coding program does a fantastic job of efficiently running samples, and it could be used to run further samples to gain more data. Since the program created the random samples itself, the samples are more truly random and therefore, are more reliable and less biased than any made by hand.

Weaknesses of the Model

One shortcoming of our model is that it only considers four characteristics. More characteristics could easily be added and assigned their own components of the Substance Index, but the threshold level would have to be raised appropriately. Another large weakness of our model is found in the numbers that we assigned to the components of the index. The components were not strictly weighted based on concrete data, but rather were loosely based on which components seemed to matter more. Weighting these categories more appropriately could greatly improve our model.

Altogether, while this model made some bold assumptions, it represents an effective and efficient way to measure likelihood for substance abuse.

3. Ripples

Restatement of the Problem

This problem calls for the ranking of the impacts of the substances, ie nicotine, alcohol, marijuana, and opioids, on the population. Using a robust metric, we will show the financial burdens of substance abuse in terms of purchasing costs and enforcement expenses, as well as the non-financial burdens of substance abuse in terms of death rates and crime rates due to specific drug use per year.

Assumptions and Justifications

1. **Assumption:** All nicotine is characterized by cigarettes.

   a. **Justification:** Cigarettes have the most accessible data and have more regulations on pack sizes and costs. Therefore generalizing all nicotine as cigarettes allows is to collect better data and simplifies our results.
2. **Assumption:** Cigarettes cause zero crime-related offenses.
   a. **Justification:** Since cigarettes are legal everywhere in the U.S., and since they impair judgement so little, very little nicotine-related crimes occur. In fact, the number is small enough to make data nearly impossible to find, justifying the generalization that cigarettes cause no crime.
3. **Assumption**: All financial expenses are composed of the cost of addiction and the cost of enforcing drug-related crimes.
   a. **Justification**: These categories are two of the biggest financial ramifications of substance abuse. The data is easily accessible and easily manipulated.
4. **Assumption**: All non-financial expenses are composed of crime-related offenses and related deaths.
   a. **Justification**: Crime-related offenses and deaths are the two main non-financial consequences of substance abuse, and data corresponding to crime and death are much more easily manipulated than those of less tangible consequences.
5. **Assumption:** The enforcement of opioids will make up a large portion of an economic burden.
   a. **Justification:** An economic burden means that the government has to pay for the enforcement of regulation for opioids. Therefore, we can assume that economic burden refers to government enforcement.
6. **Assumption:** The productivity loss in the US is synonymous with the federal enforcement loss
   a. **Justification:** A productivity loss means that the government has to pay for the enforcement of regulation for opioids. Therefore, we can assume that productivity loss refers to government enforcement
7. **Assumption**: The only people impacted by substance abuse are those use the substance and those who are arrested or killed because of the substance.
   a. **Justification**: The users of the substance and those who are arrested or killed because of it are the only quantifiable values of impact. The impact on those surround substance abusers, emotional or otherwise, is too difficult to quantify and therefore too complicated to take into consideration.

Analysis of the Problem

The best way to quantify the impacts of alcohol, marijuana, nicotine, and opioids is to split the impact between financial and non-financial ramifications. Furthermore, the financial impact can be split into the cost of addiction and the cost of enforcing drug-related crimes, while the non-financial impact can be split into crime-related offenses and related deaths. Since financial and non-financial ramifications are difficult to combine, it would be best to rank the substances' impacts separately in these two categories.

Developing the Model

We begin with calculating the financial impact of each substance. Our model for the financial impact of substance abuse for a given substance is given by the equation:

$$T_F = C_E + C_A$$

where the following variables are used:

1. T_F= Total financial costs
2. C_E=Enforcement expenditures against crimes related to a given substance per capita
3. C_A=Cost of addiction to a given substance per person per year

To find C_E, we must take the total expenses for enforcing substance abuse laws and divide it by the number of users in order to find the enforcement expenses per user per year. This is shown by the equation:

$$C_E = \frac{G_e}{P}$$

Where the following variables are used:

1. C_E=Enforcement expenditures against crime related to a given substance per capita
2. G_e=Total US government expenditures
3. P=Number of substance users

This will give us the total financial impact of each substance.

Next, we must model the non-financial impact of each substance. This is given by the equation:

$$T_{NF} = A + D$$

Where the following variables are used:

1. T_{NF}=Total non-financial impact in terms of people affected per year
2. A=Total number of people arrested due to substance abuse per year
3. D=Total number of deaths due to substance use per year

In order to find A, we took the proportion of the total arrests that were due to abuse of a particular substance and multiplied it by the total number of offenses.

$$A = A_s \cdot T_o$$

Where the following variables are used:

1. A=Total number of people arrested due to substance abuse per year
2. A_S=Percent of arrests due to substance abuse for a given substance
3. T_o=Total offenses per year

Analysis and Results of the Model

This method produced results that adequately show the impact of substance abuse, both financially and non-financially. Our assumptions are justifiable given the broadness of the problem; they allow us to hone down our data to a manageable and measurable amount. We used the cost of government enforcement of substance abuse and the cost of the addiction to find the total financial impact. We used the crime-related offenses and related deaths to measure the non-financial impact.

Our total data for this section is displayed in full below:

Table 7: Financial Impact of Substance Abuse

Financial Impacts by Substance					
Drug	**Enforcement Expenses (total in the USA per year)) (in billions of dollars)**	**Number of Users (million)**	**Cost of Addiction (per user per year)**	**Financial Impact (per user per year)**	**Ranking (based on Total Impact) (1 = most impactful; 4 = least**
Nicotine	151	37.8	$10,800	$14,794.71	2
Alcohol	20	14	$6,000	$7,428.57	3
Marijuana	3.6	37.6	$7,000	$7,095.74	4
Opioids	78.5	18	$70,200	$74,561.11	1

Table 8: Non-Financial Impact of Substance Abuse

Non-Financial Impacts by Substance					
Drug	**Percent of Total Crime Related Offenses**	**Related Deaths per Year**	**Total Crime-Related Offenses**	**Non-Financial Impact (in people affected per year)**	**Ranking (based on Total Impact) (1 = most impactful; 4 = least impactful)**
Nicotine	0	480,000	10,554,985	480,000	4
Alcohol	40	34,865	10,554,985	4,257,859	1
Marijuana	5	0	10,554,985	527,749.25	3
Opioids	20	47,600	10,554,985	2,158,597	2

[13],[14],[15],[16],[17],[18],[19],[20],[21],[22],[23],[24],[25],[26],[27],[28]

This data shows us that opioids have the largest financial impact, followed by nicotine, alcohol, and then marijuana respectively. In terms of non-financial impact, we found that alcohol has the largest effect, followed by opioids, marijuana, and lastly nicotine.

Strengths of the Model:

This model is strong because of the concrete results that it yields. Our model yielded strong, quantifiable numbers in the form of dollar values and number of people. This model can easily be applied to other years as substance use changes, resulting in numbers that can be compared from year to year. This model also allows for easy comparison between the substances themselves. Another strength of our model is that it ranks the four substances in two different rankings based on the financial and non-financial factors.

Weaknesses of the Model:

Some weaknesses of our model include not accounting for medical related expenses in financial factors for each substance which may have changed our conclusion on the most impactful substance. We only used two variables accounting for each factor (financial and non-financial) which may have inaccurately predicted the impact of each substance. More components could be taken into consideration while estimating impactfulness.

In conclusion, this model can be easily manipulated as the data changes. More components could easily be added to the financial and non-financial factors to provide a more comprehensive model. Despite some generalizations and assumptions, are model shows an effective and robust method of determining the impact of substance use.

Appendix

Code For Part 2 to Simulate a Class of 300 High School Seniors

```
//defines variables to keep track of totals
var alcoholUsers = 0;
var marijuanaUsers = 0;
var nicotineUsers = 0;
var opioidsUsers = 0;
var noneUsers = 0;
//repeats the random assignment 300 times
for(i=0;i<300;i++){
//defines the value for substance index
  var alcohol = 30;
  var marijuana = 25;
  var nicotine = 20;
  var opioids = 15;
//randomizes the risk factors
  var gender = ["male","female"];
  var rand1 = randomNumber(1);
  var income = ["high","low"];
  var rand2 = randomNumber(1);
  var mentalDisorder = ["yes","no","no","no","no"];
  var rand3 = randomNumber(4);
//assigns values depending on risk factors
  if(gender[rand1] == "male"){
        alcohol += 10;
        marijuana += 10;
        nicotine += 10;
        opioids += 10;
  }else{
        alcohol += 5;
        marijuana += 5;
        nicotine += 5;
        opioids += 5;
  }
  if(income[rand2] == "high"){
        alcohol += 20;
        marijuana += 20;
        nicotine += 10;
        opioids += 10;
  }else{
        alcohol += 10;
        marijuana += 10;
```

```
            nicotine += 20;
            opioids += 20;
  }
  if(mentalDisorder[rand3]=="yes"){
            alcohol += 10;
            marijuana += 10;
            nicotine += 10;
            opioids += 10;
  }
//tests each student's risk value against the substance use threshold
  if(alcohol>=55){
            alcoholUsers += 1;
  }
  if(marijuana >= 55){
            marijuanaUsers += 1;
  }
  if(nicotine >= 55){
            nicotineUsers += 1;
  }
  if(opioids >= 55){
            opioidsUsers += 1;
  }
  if(opioids<55 && nicotine<55 && marijuana<55 && alcohol<55){
            noneUsers += 1;
  }
}
//displays the total number of drug users for each substance
  write("Alcohol Users: "+ alcoholUsers);
  write("Marijuana Users: "+ marijuanaUsers);
  write("Nicotine Users: "+ nicotineUsers);
  write("Opioids Users: " + opioidsUsers);
  write("Used no Substances: " + noneUsers);
```

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