MathWorks Math Modeling Challenge
A program of siam

PREVIEW PAPER: AVERAGE*

The team's executive summary provides a good overview of the context and the problem, but it did not include results nor insights into the methodologies used by the team to address the questions. The three sections are not consistent. For example, in one section the impact of CO2 emissions from electric bikes is considered minimal, but later the emissions are considered to have a bigger impact. The transition from question one to question two is better than from question two to question three.

Functions are stated with little motivation or discussion, and little analysis or discussion of the implications of the functions are given. The discussion of the relative strengths and weaknesses of the models is minimal, and there is no discussion of sensitivity. The units for the different questions are not clear, and some of the functions are combined in ways that are not obviously consistent. There are no citations within the text, so it is difficult to ascertain sources or figure out which ideas were the students, and which came from other sources.

**from among the screened sample of papers examined during pre-triage work.*

Ride Like the Wind Without Getting Winded: The Growth of E-bike Use

Executive Summary

With the rise of electric vehicles, more and more people have transferred from using gas-powered vehicles to e-bikes. Users can then eliminate conventional traffic congestion and reduce carbon emissions. In the United States alone, it has been reported that e-bike sales had a 70% increase in sales and are expected to increase even more gradually.

In some of the United States' largest cities, such as New York City, Los Angeles, Chicago, and Philadelphia, more people will likely be inclined to use e-bikes to travel around more conveniently. Furthermore, the need for more eco-friendly modes of transportation urges others to invest in an e-bike. In addition to personal purchases, cities and corporations also plan to invest in e-bikes for the use of the public. Users will then find traveling from one place to another more efficient without the hassle of mobile traffic and extra-economic expenses.

To operate non-electric vehicles, the average user spends $150 - $200 monthly on gas and other maintenance expenses. Given this, the average American family will spend about $5000 annually on non-electric vehicle-based investments. Since the pandemic, the surge in supply and demand for gasoline caused gas prices to almost double and it is not expected to decrease in the near future. As an alternative, e-bikes provide a form of transportation that can perform many of the same tasks as a car.

Additionally, reducing the amount of gas-powered vehicles benefits the environment by lowering carbon emissions. The leading cause of global warming is the concerning levels of carbon emissions caused by vehicles. Not only is maintaining emission levels an essential thing for the United States, but it is also for the good of everybody living on earth.

Our first model can predict the number of bikes sold in two and five years. It used the growth over past years, the cost decrease, and how much that will change the total sales. The last thing we considered is the percentage of the population that would be buyers of e-bikes. We chose these as some of the most important factors because to determine the sales of e-bikes in the US, we needed to consider financial matters and how that will impact the likelihood of buyers. Our second model incorporates the equation that calculates the total amount of sales per year and relates to the average rise of gas prices. Our third model is the most unique compared to the other two, as it quantifies the impacts of e-bikes rather than basing the main claim on the equations provided below.

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0.1 General Assumptions

1) *No significant technological advancement will create a cheaper, more efficient, and carbon-friendly way of transportation that revolutionizes the entire market.* If this were not the case, it would change the value and desire for e-bikes. It is impossible to predict how much technological advancement will occur in the transportation industry, so we assume nothing substantial will happen. While in terms of e-bikes, there might be updates and minor upgrades, it will not drastically affect the price of the bikes.

2) *To make e-bike usage safer and more accessible, cities will implement more bike lanes and safer bike parking infrastructure.* This is also contingent upon the notion that there will not be a cut in these safety features for the foreseeable future. The bike lanes will likely double in the next two to three years. There will probably be restrictions on these aspects of city planning. These aspects of the infrastructure will make it more desirable for e-bikes to be a significant source of urban transportation.

3) *The price of electricity will increase at a constant rate, which will not make the ability to charge e-bikes more challenging in the foreseeable future.* If the price of electricity went up so much, then buying the bikes would be deemed useless. The price of charging them now is small enough that maintaining it does not make

4) *Inflation will not significantly impact the overall consumerism of e-bikes.* The inflation rate varies too much to consider sales and production. Additionally, sales prices will decrease by 10 percent yearly based on supply and demand. This makes e-bikes more attractive to consumers, considering that inflation will not significantly affect prices.

5) *Students and/or people of younger ages who use e-bikes will be using publicly or privately owned e-bikes.* E-bikes and bikes, in general, are alternative transportation forms that include younger consumers. This also is a more affordable option and eliminates the need for car insurance or other additional financial expenses cars typically require. The amount of younger ages/students who buy them is negligible.

6) *Most people purchasing e-bikes will be between 40 and 70 years old.* The study did a broad survey of users, and one of the questions was age (TREC). This study showed that a majority percentage of users aged between 40 and 70. We assumed that the credibility and people surveyed represented most of the riders in the country.

7) *The average American household owns at least one car and uses that as a primary mode of transportation.* For simplicity in calculating e-bike usage and impact, it was determined that the average family owns one gas vehicle. Previously, this may have been higher. However, many families are choosing to switch to hybrid or electric cars.

8) *The percentage of the impoverished population stays the same for the next few years.* This population significantly impacts who can afford to purchase and ride an e-bike.

9) *The number of people between 40 and 70 stays the same for the foreseeable future.* This depends on the population growth rate being negligibly the same throughout the next five years. It is improbable that there would be a significant increase in the United States population given the latest trends.

Q1: The Road Ahead

The question is to create a model capable of predicting the growth of e-bike sales. Using that model, find the total amount of e-bikes sold in 2025 and 2028.

1.1 Variables Used

Amount of E-bikes Purchased 2022 (1,000 Units) = 928

$g(t) = 928(1 + 0.45)^t$

Growth of e-bike sales

$p(t) = 928(\frac{t}{1.6 * 2.1667})$

Price of e-bikes

$b(t) = 928(0.66 * 0.324 *.884 * 1.073 * 1.005 * t)$

Consumer distribution

$c(t) = 928(\frac{t}{16.667 * 1.25})$

Gas prices as they relate to e-bike purchases

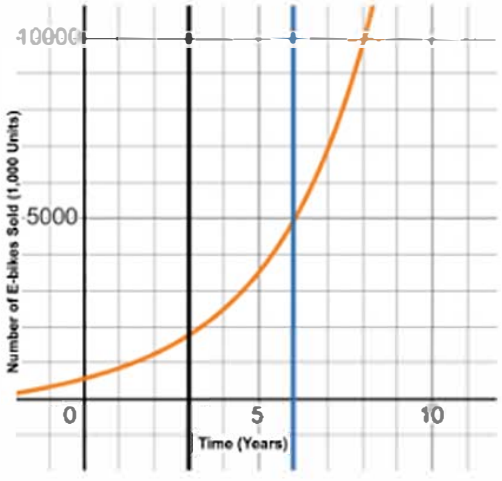
$i(t) = 928 * 1.073$

Environmental and greenwashing impacts

$s(t) = 0.5g(t) + .15p(t) + .15b(t) + .1c(t) + .1i(t)$

Total sales

1.2 Model Development



https://www.desmos.com/calculator/i8d5hmjkku

To evaluate the percent growth of e-bike sales by the year, we developed an equation that considered the most recent recorded value for sales and the percent of increase from the years 2018 to 2022. The formula below shows g(t) as the growth rate at t years, only scouting for the growth rate from years prior.

$$g(t) = 928(1 + 0.45)^{t}$$

To evaluate the percent growth factoring in the decrease in a sales price, we considered that for every 20% decrease in price, consumerism would increase 60%, and 2.1667 is the number of mounts it takes for the cost to decrease by 20%. The formula below p(t) evaluates the number of e-bikes sold if only accounting for the decrease in price-increasing consumerism.

$$p(t) = 928(\frac{t}{1.6^{*}2.1667})$$

To assess the percent growth of e-bikes, factoring in the buyers is displayed below. This equation includes that most buyers of e-bikes are from 40-70, which is 32.4% of the population. Also, 75% of the population buys eco-friendly products, and the number of people who can afford a bike is 88.4% of people. Another thing is that because e-bikes are marketed as eco-friendly and reduce carbon emissions, this factor would increase consumers' want by 7.3%. The last factor includes that the population growth is .5% each year. This formula only considers the number of people buying e-bikes.

$$b(t) = 928(0.66 * 0.324 *.884 * 1.073 * 1.005 * t)$$

To evaluate the sale equated to the increase from the gas price because more people are turning to every option that includes e-bikes. This equation considers that every 16.667 years, the gas price will increase by 25%, which would cause the rate of people buying e-bikes by 25%.

$$c(t) = 928(\frac{t}{16.667^{*}1.25})$$

To evaluate the total sales, including the other equations g(t), p(t), and b(t) so that each one factor into the whole deal. The constant before each equation is how much that factor affects the number of e-bikes. The most crucial element in this equation is the past increase in e-bike sales, which has the most impact on the final numbers. The p(t) and b(t) have the same constant because they are factors that matter the same, and one is not more important than the other. Then we also considered the changing gas price in c(t) and the fact that e-bikes are marketed as eco-friendly in i(t), which would increase the number of people interested in buying.
The constants add up to one because each of the different equations uses the same starting amount, so they were added together to get a final number.

$$s(t) = 0.5g(t) + .15p(t) + .15b(t) + .1c(t) + .1i(t)$$

Table 1.2.1 - E-bike sales per year in the United States

Year	E-bike Sales (by 1000 units)
2018	369
2019	423
2020	416
2021	750
2022	982

1.3 Results, Summary, and Discussion

To evaluate the increase in sales of the e-bike in 2 and 5 years we broke it down into five categories. The first is based on previous years' increases, using the data from 2018-2022 to find a growth rate, then using the exponential growth equation to predict e-bike sales in 2025 and 2028. The next thing we decide on doing is starting to include other factors relating to the sales of bikes. All of the other factors positively increase the sales of e-bikes.

The first factor we looked at is that the price of e-bikes will decrease over time, increasing consumer interest. This is based on when a product decreases price by 20%, buyer interest increases by 60%, and it would take 2.1667 years to have the price of the e-bike decrease by 20%. The next factor we looked at is the percentage of the population that would be consumers of e-bikes.

For that, we looked at some statistics which showed that most of the consumers of e-bikes were from the age of 40-70 years old, and so we had to find that the percentage of the population within that age range is 32.4%. Then we look at the amount of the population that is not in poverty because they are the people who can afford an e-bike. The next part of this, we factored in the number of people interested in buying eco-friendly products, would be 66%. The next factor in this was that because this is eco-friendly, it would increase buyer interest by 7.3 percent. Then the last factor in this equation was that the population is growing by .5%, which we had to consider.

To get the results, we combined our five equations in different ratios based on what we deemed as more important factors than each other, and what results of model one were that there would be 1677 thousand e-bikes sold in 2025 and 4838 thousand e-bikes sold these are our estimated values.

Q2: Shifting Gears

The question is to identify the causes of the growth of e-bike sales. Some significant factors include environmental effects, gas and electricity prices, personal finances, overall cost, and the "coolness factor." To reason, the identified cause, use mathematical modeling to prove its effect on the growth of e-bike usage.

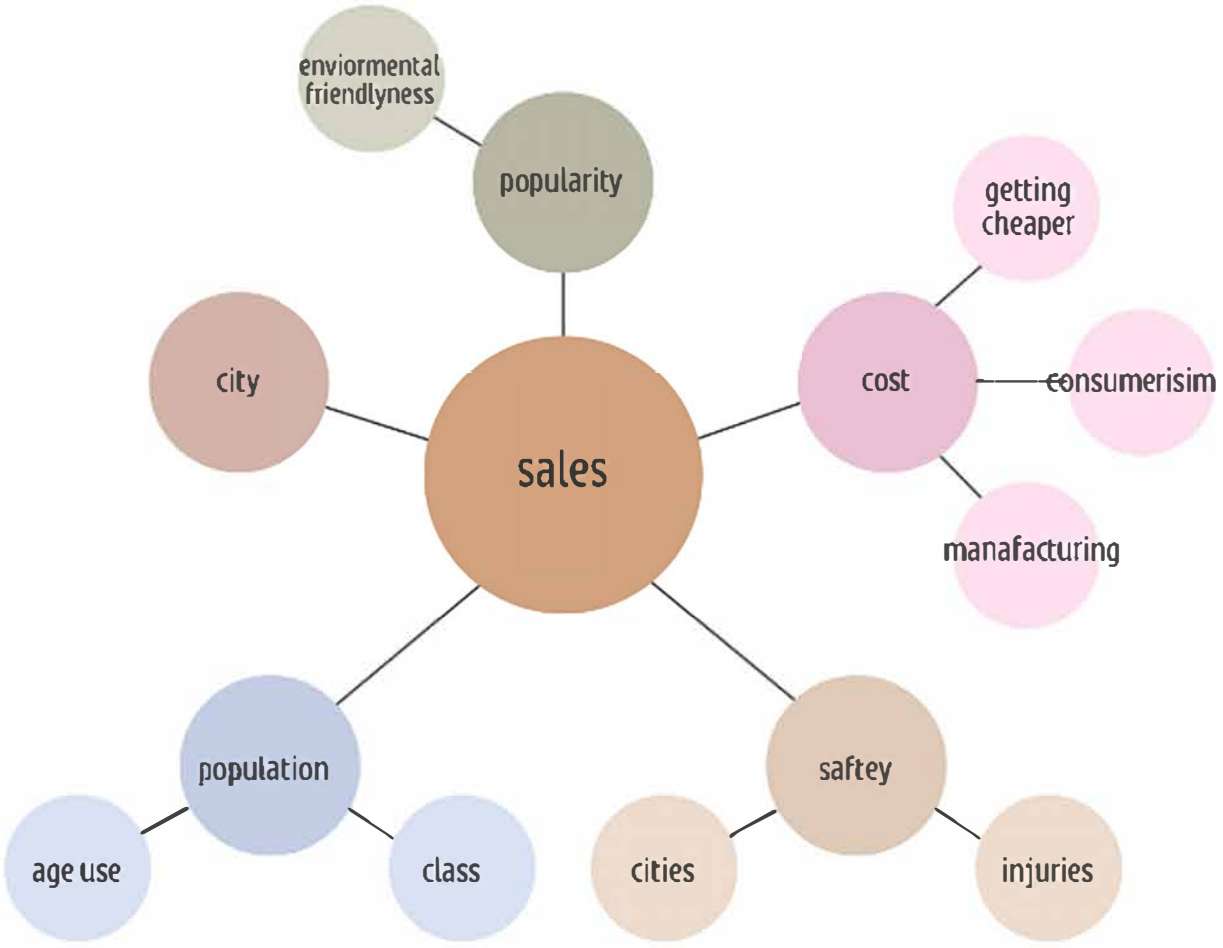
From an environmental perspective, e-bike travel is nearly six times more efficient than transportation by a gas car. By maximizing e-bike travel, it is possible to save 24.4 million metric tons of CO_2 emissions per year. This equates to about 580 kilograms saved per person. One can also infer that the average family-sized four-by-four car emits about 200 grams of carbon dioxide per kilometer. The number of people in the said car is negligible regarding carbon dioxide emissions due to the car's weight. For example, if we were to take this exact gas vehicle and travel the 154.2 kilometers from the Philadelphia City Hall to the Empire State Building, there would be about 30,000 grams of carbon dioxide emissions. For an e-bike to travel this distance, it would only take between 95.8 and 190 grams of carbon dioxide to emit. That quantifies over 300 times the amount emitted from a gas car compared to an e-bike. This is important to point out because eco-friendly culture has become more prevalent. If people knew buying an e-bike would make an environmental impact, they would be more willing to buy a bike. This growing environmentally friendly agenda has been growing at a fast rate. This is seen through the election of pro-environmental officials using their power to fight climate change.

Over the past ten years, gas prices would have increased linearly. Today's average price is $2.22 per gallon, which can cost anywhere from $32.1-$50.55 to fill up a full tank of gas, which translates to about 375 miles.

On the other hand, electricity is priced at around $0.17 per kilowatt. Depending on an electric bike's battery capacity, it will typically take up to 800-watt hours to charge the battery. This will set the bike rider back 6.8 cents-13.6 cents; for one charge, the rider can get anywhere from 20-80+ miles before charging again.

For the past few years, cars have been selling over the manufacturer's suggested retail price (MSRP). The average price that dealers charge for these automobiles is between $35,000-$50,000+.

A new e-bike can range anywhere from $600-$10,000+. A wide range of price options changes the bike's power, battery life, and overall quality. Regarding vehicles, there is no indication that these increased prices will come down in the foreseeable future. E-bikes have decreased their price by 10% between 2020 and 2021. While car companies plan to increase their prices, E-bike companies will keep lowering their costs until they are affordable for most people.



2.1 Variables Used

Equation from model one including data from research that looks into what would affect sales interest.

$p(t) = 928(\frac{t}{1.6*2.1667})$

Price of e-bikes

$b(t) = 928(0.66 * 0.324 *.884 * 1.073 * 1.005 * t)$

Consumer distribution

$c(t) = 928(\frac{t}{16.667*1.25})$

Gas prices as they relate to e-bike purchases

$i(t) = 928 * 1.073$

Environmental and greenwashing impacts

2.2 Model Development

See equations above.

2.3 Results, Summary, and Discussion

To identify the causes of the growth of e-bike sales of the e-bike in 2 and 5 years, we broke it down into three categories. The first is looking at it from an environmental perspective, and for this, we found that maximizing e-bike travel makes it possible to save 24.4 million metric tons of CO_2 emissions per year. The next category looked at the constantly high gas price vs. the meager price of electricity. Along with the price difference, electricity is renewable and will never run out. Gas, on the other hand, eventually will, and as we get closer and closer to our last drop, the prices will continue to increase. The last category was the cost difference between cars and e-bikes. E-bikes run lower than new cars; the average bike is around $1,800. Moreover, as inflation and the cost of material for cars rise, new costs are at an all-time high. E-bikes are the more financially feasible option.

Q3: Off the Chains

The question that is tasked here is to consider how other forms of transportation, such as gas vehicles and regular bikes, may be reduced. Quantify the relevant results for reduced use, such as carbon emission and traffic congestion.

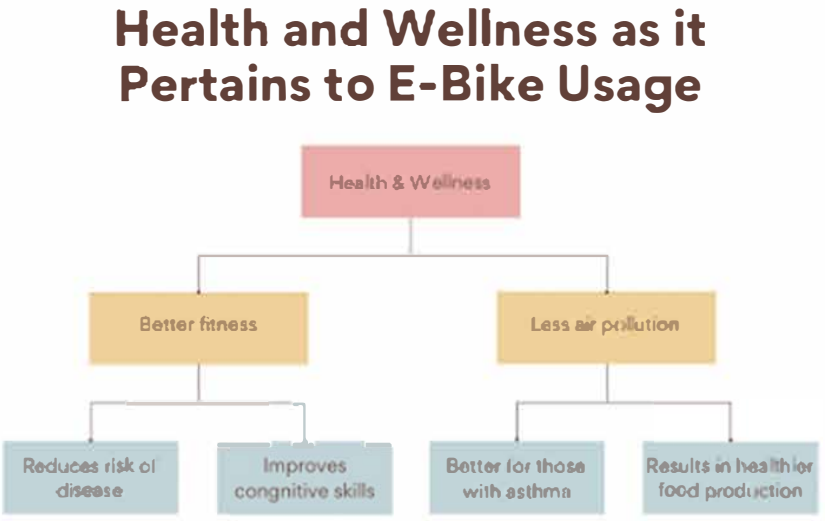
As more and more people use e-bikes or other electric vehicles, other modes of transportation, such as gas-powered cars, regular bikes, and public transportation, are bound to decrease. Reducing this other transportation also has beneficial effects such as a decrease in carbon emission, decongestion of traffic, and other health benefits. This transition from gas-powered to electric vehicles has more advantages than disadvantages.

Last year in 2022, the reported national carbon emission increased by 1.3% from the previous year. The emission will continue to grow in the upcoming years unless immediate action is taken. The addition of e-bikes reduces the amount of carbon put into the air because it is entirely powered by electricity and reduces 0% carbon. Statistics have shown that if 15% of cars were exchanged for e-bikes, carbon emissions could reduce by 11%, about 900 metric tons per day.

The growth of e-bikes in the city would also lead to decreased traffic congestion. This will increase the country's efficiency in getting to where people want. Fewer cars will be on the road if more people start using e-bikes for even their short-distance traveling.

As e-bikes become more common, 100% of the overall health and wellness of the general population will improve. It has been proven that individuals who sit any less than the average person and/or have some form of physical activity regularly will have numerous health benefits. These benefits include, but are not limited to, neurological health, weight management, and

strengthening one's body to aid with daily tasks. When more e-bikes are used, air pollution production will decrease. Less pollution will better the lives of many, especially those with asthma.



3.1 Assumptions

1) *The number of e-bike sales sold from 2012 to 2028 will represent the majority of bikes on the consumer market.* Since the growth of sales of e-bikes was found to be so substantial by 2028, any bikes sold before then are deemed negligible.

2) *Purchasing an e-bike means a total remission in the use of cars and the production of carbon dioxide released into the atmosphere from those vehicles.* If people purchase the e-bike, it is assumed that they will not use their car at all. Since the bike is a relatively expensive purchase, eco-friendly and cost-saving.

3) *Before purchasing e-bikes, the users, even though deemed eco-friendly, put the average American amount of 4.6 metric tons of carbon dioxide from gas cars into the air.* Even though these users are more eco-friendly, the amount that owns electric cars will not impact the final value significantly. This is because the number is negligible, and assuming some driver's cars put more than the American average carbon dioxide emissions.

4) *There is no substantial technological advancement that makes gas cars produce a lower amount of carbon dioxide that would make e-bikes useless.* It is reasonable to assume that nothing like this occurs or would change the whole industry. So, we used the average amount of carbon produced per car in the US for 2022.

3.2 Variables

We decided to find the average emission saved per bike because the model above is only partially accurate and would be easier to quantify regarding bikes.
~192 g per kilometer is the average carbon emission of a car
~ 1.23 g per kilometer is the average emission of a bike.
192-1.23 = 190.8
The average emission of carbon per kilometer per bike is 190.8g saved.

The average car puts around 4.6 metric tons of carbon dioxide annually into the atmosphere. If each person who bought an e-bike replaced their car entirely with their bike, the equation for carbon emission would be 99905 g of carbon saved.

3.3 Results, Summary, and Discussion

For question three, we identified the difference in carbon emissions between cars and e-bikes. The difference is almost scary; if 15% of cars are exchanged for e-bikes, 900 metric tons are saved from going into the atmosphere daily! This would greatly help people with health conditions such as asthma because if the air is full of carbon emissions, not only will people with asthma be affected, but the elderly, babies, and everyone could be affected. Even new diseases Could come out of this. Furthermore, humanity knows we are not ready for another virus, as we are still recovering from Covid-19.

Conclusion

5.1 Further Research

Holistically speaking, this paper has described the ideal ways to utilize e-bikes. In our original plan, we hoped to research specific statistics about the top ten major cities in the United States. Among these cities is Portland, Oregon, one of, if not the leading city in cycling culture. Bicycling Magazine has awarded Portland the number-one biking city in America several years in a row. So, how do they cultivate this culture? What have city planners done to make the roads more accessible? How can this be replicated in other cities in the country?

Nationally, about 0.5% of commuters bike to work. This percentage is 6.7% in Portland, over twelve times the national average. Many of these statistics are due to city planners, who have dedicated 385 miles of bikeways throughout the city. 162 miles of said paths are bike lanes. In the next five years, 95 more bike paths will be installed. 35.5 miles have been built of these paths with safety features to further separate bikers from traffic, such as bushes or railings. There are 6500 public bike racks to incentivize safe bike storage when stopping in public spaces. Every Sunday, the majority of parkways are closed for public use. 90% of these individuals are cyclists.

By providing safe and accessible options for bikers, Portland has been made one of the best cities for cyclists nationwide.

We offered a solution to calculate the growth rate of e-bike sales through our models. With the models, we specifically found sales in 2025 and 2028. We used an exponential and a linear model to predict the overall growth rate at a given time using the factors of buyers' percentage, overall growth rate from the past year, and the decrease in price relating to increasing consumer buying.

5.2 Possible Errors

For the project, we used multiple websites, and some of their content may or may not have contradicted each other. On the prompt document, a spreadsheet was attached containing information for bike sales by region and year, US costs by company name, disposable income, battery and gas prices, and usages of different types of modes of transportation by the year. Most of our data came from this provided spreadsheet, and the remaining components came from external sources. For question one, we used all the information from "E-bike Sales Data Across the World" from the United States to create a change rate. That constant is represented as 0.45. This was determined by the overall change from 2018-2022. This poses an error for miscalculation because it may not have been a constant rate of change. In between the time interval was the pandemic, which could have varied the numbers lower than normal because of the inactivity of vehicles during quarantine. For question two, all the data collected and used were from external sources, so that causes everything to be inaccurate potentially. Similarly, for question three, there was a combination of use from the provided evidence and external resources. External sources are still valid methods, but their accuracy may be compromised.

5.3 Ideal Additions

Given the time constraint of 14 hours, our research may not have been as thorough as we would have liked it to be. For question one, we spent two hours discussing and working on data research and forming a more well-rounded group of equations. It might not look like it from an outsider's perspective, but this part was highly rushed for us. For question two, similarly to question one (because they were so interconnected), more in-depth research about factors that impact e-bike sales could have improved our modeling drastically, letting us add additional factors into models one and two. Rather than finding a few impactful sources, we mostly skimmed through many articles. For question three, making more accurate accusations would have positively impacted our argument, and evaluate our number per bike but because of time constraints and because of the complexity of model 1. Overall more time and an excessive amount of research would greatly help our models.

5.4 General Conclusion

In recent years, the number of users of e-bikes and other non-gas vehicles has risen, and policymakers are interested in making a change. If enough people own and use e-bikes, policymakers will begin investing in more bike lanes and, if conditions allow, implementing tax incentives. For various reasons, reducing the use of non-gas vehicles will benefit the environment and people's health and improve an individual's lifestyle. The e-bike product is inclusive to all, but most benefactors are people who live in populated regions, such as busy cities, and middle-aged people between 40-47. We also included students and other adolescents as one of the top users of public e-bikes precisely. To answer the three questions, we created models that quantify the number of e-bikes sold in thousands of units by the year.

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