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DEPARTMENT OF ECONOMICS

EVALUATING THE EFFECTIVENESS OF AN AUTONOMOUS VEHICLE MANDATE IN REDUCING THE ECONOMIC AND SOCIETAL COSTS OF CAR ACCIDENTS

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ABSTRACT

In 2010, the United States faced $242 billion in economic costs due to motor vehicle accidents. This includes the costs of over 30,000 fatalities, 4 million injuries, and 24 million damaged vehicles. If the costs were expanded to include quality-of-life evaluations, the negative impact of car crashes in the U.S. in 2010 came close to $1 trillion. Year over year, these costs continue to be faced as total vehicle miles traveled increase and accident rates hold steady.

Today, society is at a pivotal point where new advancements in technology have the ability to reverse this trend for good. Over the next forty years, there will be a rapid rise in the development and adoption of self-driving vehicles. This new technology will have implications across the economy that are not just limited to the loss of driving occupations. One of the less considered impacts on the economy from autonomous vehicles (AVs) is the reduction in car accidents. Studies have shown that 93% of accidents stem from human error. As adoption levels of AVs increase over time, the number of accidents will begin to decline drastically with less people behind the wheel.

The current legislative and regulatory landscape has become increasingly more in favor of AVs and should allow for AVs to enter the market by 2020. The next large question that needs to be answered is should the government support initiatives to increase AV adoption and if so how. This thesis develops a model to predict AV adoption rates over the next four decades with and without a federal mandate declaring all new vehicles sold after a certain date must be autonomous. Forecasts of vehicle miles traveled, average cost per accident, and accident rates are then applied to estimate how substantially a mandate would reduce total accidents and their associated costs.

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Chapter 1

Introduction

Modern Vehicles

The United States has had a long history with automobiles dating back to the late 19th century. Initially, automobiles were considered a luxury good with vehicles by Duryea Motor Wagon Company, Oldsmobile, and Cadillac predominately being purchased by the wealthy. This changed in 1908 when Henry Ford introduced the *Model T*. With Ford's use of assembly lines and interchangeable parts, automobiles transformed from a luxury good for the wealthy into an affordable good accessible to the middle class. From its introduction in 1908 to 1927, over 15 million *Model Ts* were manufactured and sold. Additionally, many other manufactures[1] began entering the market offering a greater selection of affordable automobiles beginning the era of the modern automobile (Foellmi, Wuergler, & Zweimüller, 2014).

Undoubtedly, the introduction of automobiles has had a large positive impact on the American economy. Automobiles freed Americans of their geographical limitations allowing cities to expand into suburbs and for trade to increase across the country. However, automobiles have also come at a great cost to both the environment and our safety. This thesis will focus specifically on the negative impact of automobile accidents.

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[1] General Motors, Chevrolet, Lincoln, Dodge, Mercury, Chrysler

Car Accidents Overtime

It is important to note that although the total economic and societal impact of car accidents in the United States has been increasing overtime, this is driven by increases in the total number of miles driven not declines in automobile safety. Over the last 100 years, developments in car design, government regulation, and infrastructure have allowed for automobiles to become an increasingly safer mode of transportation.

This increase in automobile safety is best displayed by the fatality rate per hundred million vehicle miles traveled. The National Highway Traffic Safety Administration (NHTSA) reports there was 1.18 fatalities per hundred million vehicle miles traveled in 2016. Although 1.18 represents a large number of deaths due to the high number of total miles traveled, this is down from 24.09 fatalities per hundred million miles traveled experienced in 1921, the first year NHTSA reports this metric ("Fatality Analysis," n.d.). If the 1921 fatality rate was experienced at the 2016 level of miles driven, there would have been over 750 thousand fatalities due to car accidents.

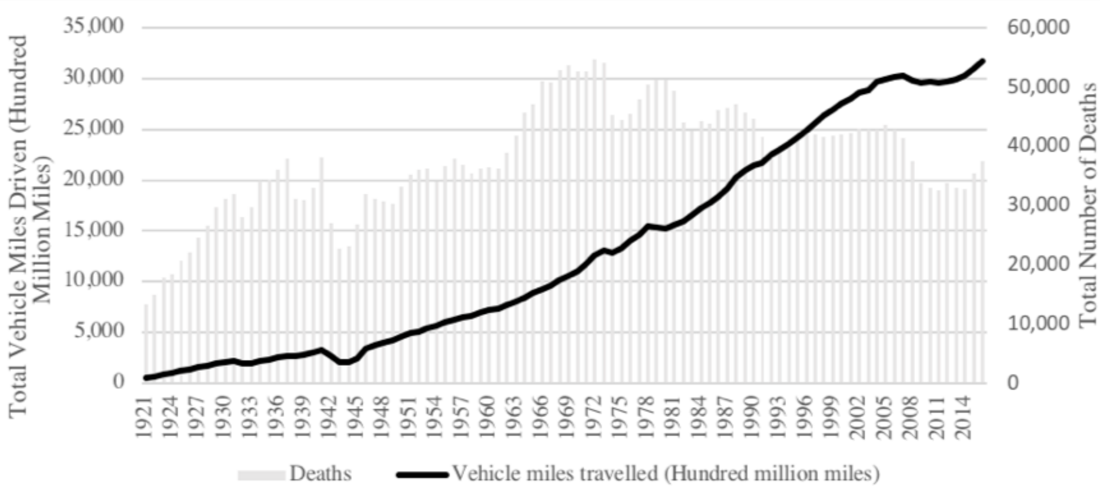

Figure 1. Miles Driven and Vehicular Deaths 1921 to 2016 ("Fatality Analysis," n.d.)

Figure 1 displays how rapidly the use of automobiles increased over time and the corresponding number of vehicular deaths. This reveals again that increases in total miles driven do play a role in the number of fatalities; yet, it is clear that increasing safety has to be playing a large role. Today, the US experiences similar numbers of vehicular deaths seen during the 1930's with over ten times the number of miles driven.

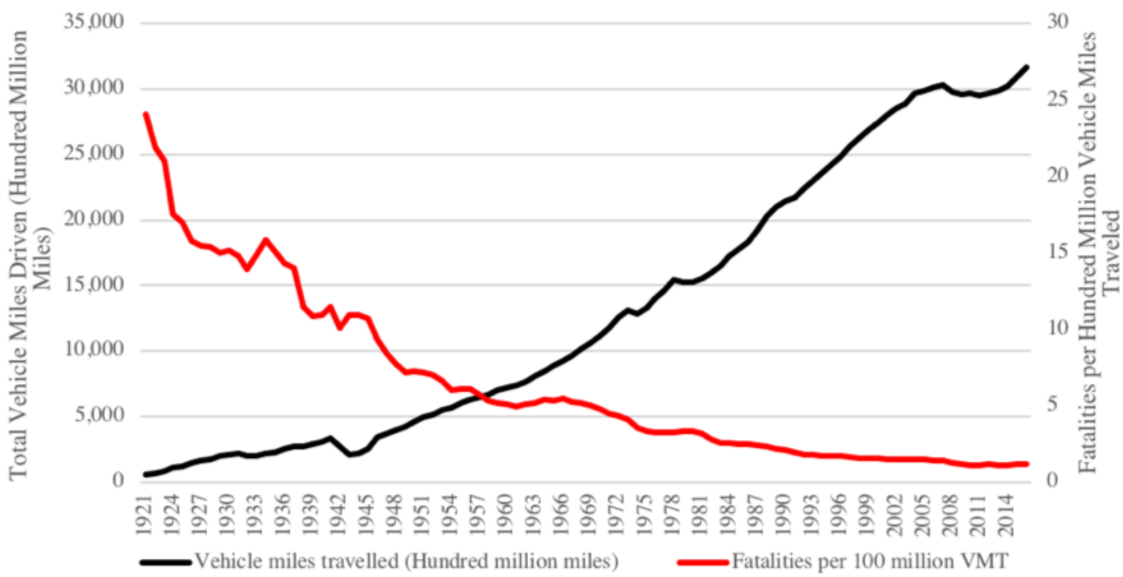

Figure 2. Miles Driven and Fatality Rate 1921 to 2016 ("Fatality Analysis," n.d.)

Figure 2 displays how substantially the safety of automobiles has increased in this period of time. This is a result of both advances in vehicular safety design as well as government policy. Some notable development occurring over this period of time are include headrests, seat belts, crumple zones, airbags, and an increasing number of federal regulations mandating these features for new vehicles. It is clear that early safety feature development played a huge role in the declining fatality rate, but over time new developments have not made as substantial of a difference. More recently, the fatality rate has remained relatively stable at around 1.1 fatalities per hundred million miles traveled.

The plateau in this fatality rate is likely due to what could be considered the systematic risk of automobiles: humans. A majority of the developments in car safety over the last hundred years have been aimed at making automobiles better protect their passengers should they be in an accident. Few improvements on the car side have been catered towards reducing the number of accidents. The government has created traffic laws to better control this human element of car accidents, but it is clear that they can only go so far in promoting safe driving behaviors. Currently the NHTSA estimates that 94% of car accidents are contributed to driver error, the remaining 6% is comprised of vehicle component failure and weather conditions ("Critical Reasons for Crashes," 2015). The clear next step for car safety is to tackle the human error side of automobiles and this is where autonomous vehicles (AVs) enter.

Current Regulatory Environment

Up until recently, one of the darkest clouds hanging over the future of AVs was the current United States regulatory environment. The current landscape for AV regulation is highly fragmented with differences between individual states, the federal government, and regulatory agencies.

In the absence of federal laws regulating the testing and sale of AVs, 21 states have passed their own unique AV legislation and nearly all of the remaining states are in the process of creating their own ("Autonomous Vehicles," 2018). The large number of unique AV laws in place has made navigating the legality of AVs incredibly difficult for companies developing the technology. Presently, these companies' cars may be perfectly legal in one state but outlawed in others. Not only does this hinder the testing of these vehicles but if this is not resolved prior to the market release of AVs it is possible that AV owners will not be able to drive across state lines.

Towards the end of 2017, both the House of Representatives and the Senate began making progress on AV bills. On September 6th, the House of Representatives passed the Safely Ensuring Lives Future Deployment and Research In Vehicle Evolution (SELF DRIVE) Act ("Autonomous Vehicles," 2018). The SELF DRIVE Act's goal is to encourage further AV development and provide an initial regulatory environment. The bill blocks states from banning AVs, exempts a company's first 100,000 AVs from existing safety standards, and requires AV manufacturers to develop plans to thwart cyber-attacks ("H.R. 3388," n.d.). The senate version of the bill, the American Vision for Safer Transportation Through Advancement of Revolutionary Technologies (AV START) Act is still in committee but has the same goals as the SELF DRIVE Act with a few slight differences. The first is that trucks are excluded in the bill, presumably to simplify the passage of the bill since trucking faces larger political opposition. The second is that it does not discuss data privacy (McCormick, 2017). This marks the beginning of congress taking AV seriously and is an indication that AV entrance into the market will be supported.

Lastly, the Department of Transportation and specifically the NHTSA has been supporting AV development since early 2013. The NHTSA has recently updated its AV guidelines with its report *Automated Driving Systems: A Vision for Safety*. The NHTSA sees AVs as one of the key elements in continuing to meet its mission of "Save lives, prevent injuries, reduce vehicle-related crashes." The NHTSA has committed to investing $4 billion over the next decade to help accelerate the development and adoption of AV ("Autonomous Vehicles," 2018).

Additionally, in October 2016 the NHTSA, in partnership with the National Safety Council, launched the Road to Zero initiative whose goal is to eliminate all traffic fatalities by 2050. To do this, the Road to Zero is relying heavily on the development and adoption of AVs ("Road to Zero Coalition," n.d.).

Paper Goals

With the newly optimistic regulatory environment for AV, the future is bright for the safety of our roads. Due to the previously ambiguous regulatory environment, research on car accident reduction has been mainly focused on the acceleration or delay of AVs' introduction in the market. Now that the market entrance appears to be receiving government support, the next logical step is to analyze the ways in which the government can increase AV adoption in order to reduce the impact of car accidents as much as possible. There are many ways in which the government can do this including subsidies, development grants, and a federal mandate. This paper will focus specifically on the impact of a government mandate declaring that all cars sold after a certain date must be autonomous.

To do this, this paper will work towards developing two models of AV adoption: one with and without a federal mandate. Additionally, this paper will look into the average cost per car accidents, car accident rates for both non-autonomous and autonomous vehicles, and projections of future total miles driven. All these variables will be combined together in our model to calculate the total economic and societal costs for both adoption cases and compare the two in order to see how substantial of an impact the federal mandate would have.

Chapter 2

Average Costs of Automobile Accidents

Total Cost

The most recent analysis of the economic and societal impact of automobile accidents published by the NHTSA was released in 2015 on the 2010 United States car accident data. In this analysis, the NHTSA estimates the economic cost of motor vehicle accidents at $242 billion. This cost represents the present value of lifetime economic costs that are a result of the 32,999 fatalities, 3.9 million non-fatal injuries, and 24 million damaged vehicles with 2.97 billion miles driven. This represents a rate of 1.11 fatalities per hundred million miles driven (Blincoe, Miller, Zaloshnja, & Lawrence, 2015).

A breakdown of the components of the $242 billion in total economic costs calculated is shown in Figure 3. The figure reveals that the economic costs are more widespread than just property damage and that many other aspects of the economy are also indirectly affected. An additional $594 billion in societal costs are contributed to these accidents when quality-of-life evaluations are considered. This brings the total economic and societal cost of car crashes in 2010 to $836 billion (Blincoe et al., 2015).

A full economic and societal cost analysis has not been conducted for more recent years; however, both the number of vehicle miles traveled and fatalities have increased to 3.17 trillion miles and 37,461 fatalities in 2016. This represents a rate of 1.18 fatalities per hundred million miles driven. The total number of car accidents for 2016 has not been published[2], but the total is

[2] It takes the NHTSA two to three years to consolidate each states accident data.

expected to increase as it has done in the past with similar increases in total miles driven ("USDOT Releases," 2017). These increases indicate that the negative economic impact of car accidents has increased over the last 7 years.

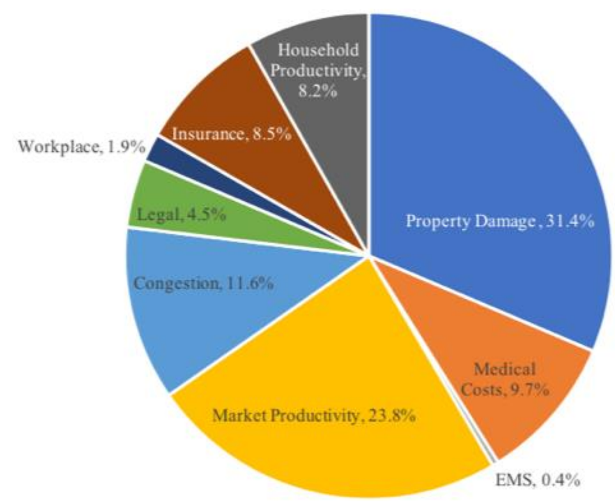

Figure 3. Breakdown of 2010 Total Economic Costs of Automobile Accidents (Blincoe et al., 2015)

Total Number of Accidents

The total costs described in the previous section were based on the total number of police reported accidents as well as the estimated number of unreported accidents. The crashes were divided into three categories: fatal, injury, and property-damage-only (PDO). Table 1 shows the breakdown of each of these categories. Ultimately, the NHTSA determined that the $836 billion in economic and societal costs to the US in 2010 was a result of 13.6 million car accidents (Blincoe et al., 2015).

Table 1. 2010 Accident Breakdown (Blincoe et al., 2015)

	Police-reported	Not Police-reported	Total	Percent of Total
Fatal	30,296	0	30,296	0.22%
Injury	1,791,572	1,178,391	2,969,963	21.89%
PDO	4,255,495	6,310,019	10,565,514	77.88%
Total	6,077,363	7,488,410	13,565,773	100%

Average Cost

Naturally, the three categories of car accidents in table 1 vary substantially with the average cost per accident. Fatal accidents can result in millions of economic and societal losses while PDO accidents can be as low as a few hundred dollars with injury-only accidents falling somewhere in between. Intuitively, this means that for modeling purposes it would make sense to develop three average costs per accident; conversely, though because the percentage of each type of accident experienced is relatively stable over time[3] an average cost for all accidents will be applicable in the model being developed.

Retrieving the average cost per accident figure is fairly simple; take the total costs and divide by the number of accidents. In doing so, we get an average economic cost per accident of around $17,800 and an additional $43,800 in societal costs per accident. The high averages clearly show that the fatal and injury-only accidents are driving up the total average cost.

[3] This will be further substantiated in chapter 4 with recent historical data.

Future Average Cost

In order to best be able to model the future average cost per car accident, it is worth looking into how the costs have increased over time. Prior to the release of the NHTSA report detailing the cost of car accidents in 2010, the last year analyzed was 2000. For the year 2000, the NHTSA determined there was a total of 16.4 million car accidents whose economic impact totaled 230.6 million in economic costs (Blincoe, Seay, Zaloshnja, Miller, Romano, Lutcher, & Spicer, R, 2002). This averages out to a cost of around $14,100 per car accident.

Although the total economic cost of accidents only increased by 5% over the ten-year period between reports, this was driven by declines in the total number of accidents. The average economic cost per accident over this period of time increased by 26.5%. This represents a 2.38% compound annual growth rate. This 2.38% growth will be used to estimate the economic costs in the model utilizing the formula below.

$$\boldsymbol{Average\ Economic\ Cost\ per\ Accident\ in\ Year\ T} = \$\mathbf{17,800} \times \mathbf{1.0238}^{\boldsymbol{T}-\mathbf{2010}}$$

Utilizing the 2.38% growth rate should be conservative for forecasting future economic costs. This is because the largest economic cost drivers detailed in figure 3 are property damage, market productivity, and medical costs. Historically, these costs have been growing at above 3% and it is expected they will continue to do so moving forward.

The report detailing the costs for 2000, did not go as far into societal impacts as the 2010 report and did not provide a total societal cost. As a result of this, we are unable to calculate the growth rate in societal costs for this period of time. However, the societal impact of car accidents is mainly driven by the statistical value of a life with the entire amount being lost in the case of fatal accidents and partial losses with quality of life impacting injuries. In this model, we will use the same growth rate as economic costs to be conservative, although the 2010 NHTSA report assumed a 3% growth. The formula used for societal costs is below.

$$\boldsymbol{Average\ Societal\ Only\ Cost\ per\ Accident\ in\ Year\ T = \$43,800 \times 1.0238^{T-2010}}$$

For the context of this paper, economic and societal costs represent two unique sets of costs. Technically, economic costs would be considered a part of societal costs but for this model we have made the two groups mutually exclusive to better analyze the impact of each. The true societal cost would be both the economic and societal costs calculated summed together.

Chapter 3

Autonomous Vehicle Adoption

Market Entrance

Unlike the *Model T,* autonomous vehicles are unlikely to abruptly enter the market and transform it overnight. Instead, each year new models of cars will begin to have an increasing number of autonomous features until eventually the cars will be fully autonomous and are able to navigate from point A to point B with no driver assistance.

SAE International, a professional association that develops standards for engineering professionals, defines the five different levels of vehicle automation. These standards have since been adopted by the Department of Transportation (DoT) and the NHTSA. The five levels are outlined in Table 2. The levels show that as AVs develop, the role of the driver will move from fully controlling the vehicle, to monitoring the vehicle, to then giving full control over to the vehicle.

Table 2. Levels of Vehicular Automation (Faheem, 2017)

Level	Title	Description
0	Driver Only	• Driver is responsible for the vehicle. Controls lateral and longitudinal movement at all times. • System may provide alerts and warnings when driver fails to exercise proper control.
1	Driver Assistance	• Driver is responsible for the vehicle. Controls lateral and longitudinal movement at all times. • System can support lateral OR longitudinal control.
2	Advanced Driver Assistance	• Driver is responsible for the vehicle. Controls lateral and longitudinal movement. May hand some control over to the system. • Must actively monitor system performance and retake full control where necessary. • System can control lateral or longitudinal movement in specific use cases.
3	Advanced Driver Assistance	• Driver is responsible for the vehicle. Controls lateral and longitudinal movement. Can hand full control to the system. • Must actively monitor system performance, retaking controls as necessary. • System can control lateral AND longitudinal movement in specific use cases. Where system exceeds performance limits, it will hand control back to the driver.
4	Highly Automated	• Driver is only responsible, and exercises control when the system is not in use. • System can control lateral AND longitudinal movement in specific use cases. It will not require driver intervention during this time.
5	Fully Automated	• System can control lateral AND longitudinal movement in all use cases. Driver intervention is not needed.

Roads today are comprised of a mix of automation levels 0 to 2. Level one features such as parallel parking, cruise control, and obstruction warning are common on many new vehicles. Some luxury car manufacturers have begun offering level 2 features such as automated lane guidance, accident avoidance, and driver fatigue detection. Google and Uber have driven hundreds of thousands of miles with level 3 and 4 automated vehicles on specifically mapped routes with human drivers at the wheel to take control if necessary (Litman, 2017). Automobiles with automation levels 4 and 5 are already in development by numerous companies including Audi, BMW, Cadillac, Ford, Google, GM, Mercedes-Benz, Nissan, Toyota, Volkswagen, and Volvo. Specifically, Nissan and Volvo have announced they intend to have commercially viable autonomous vehicles by 2020. With prices drops in the years following AVs introduction to the market, fully AVs may be available to the mass market as early as 2020 to 2025 (Fagnant & Kockelman, 2015).

Market Penetration

There is an abundance of literature predicting the market penetration of AVs following their introduction to the market. There are four different types of these predictions. The first analyzes previous automobile developments and their historical market penetration to qualitatively predict AV adoption. The second focuses on the benefits of AVs and customers perceived value through surveys to predict adoption. The third utilizes a more mathematical approach with diffusion models to show how AVs will penetrate the market. Lastly, the fourth kind of predictions are from the industry itself from various automobile manufacturers and financial institutions. These final types of predictions typically do not go in depth on their projection method but are still valued by investors. This section of the paper will explore the highest regarded papers in each of these categories and their findings, then will compare and contrast to ultimately find the most likely prediction.

Historical Based Predictions

One of the most sited studies on AV adoption is by Todd Litman with the Victoria Transport Policy Institute. In this study, Litman analyses five previous vehicle technologies and their adoption over time: automatic transmissions, air bags, hybrid vehicles, subscription vehicle services, and vehicle navigation systems. These five technologies represent a wide variety of deployment cycles, cost premiums, and market saturations. The comparison between them revealed that new technologies take decades to reach their market saturation and, unless the government mandates a certain feature, few become universal. AVs are the closest to automatic transmissions with increasing performance and decreasing premiums over time as well as a high levels of market saturation (Litman, 2017).

Additionally, Litman examined vehicle turnover. Median vehicle operating lives increased from 11.5 years in 1970 to 16.9 years in 1990. The lives of current vehicles are not yet known but based on historical increases new cars may have upwards of 20-year lifespans. Long vehicle lifespans result in it taking three to five decades for new technologies to penetrate 90% of operating vehicle fleets. Interestingly, AV adoption may be higher in developing countries who are expanding their fleet size since that is not inhibited by existing cars like they U.S. market (Litman, 2017).

Table 3. Victoria Transport Policy Institute Predictions (Litman, 2017).

Stage	Decade	Vehicle Sales	Vehicle Fleet	Vehicle Travel
Available with large price premium	2020s	2-5%	1-2%	1-4%
Available with moderate price premium	2030s	20-40%	10-20%	10-30%
Available with minimal price premium	2040s	40-60%	20-40%	30-50%
Standard feature included on most new vehicles	2050s	80-100%	40-60%	50-80%

The final predictions are shown in Table 3. Litman believes that fully AVs will be available and legal to drive in 2020 but will have limited performance and operability as well as high price premiums resulting in little vehicle sales. Then as performance improves and costs decline in the coming decades, sales will increase until ultimately AVs reach a high level of market penetration due to the great number of associated benefits with the technology (Litman, 2017). The inclusion of the vehicle fleet and vehicle travel of AV in these predications will better allow for an analysis of increased road safety.

Consumer Preference Based Predictions

The study titled “Forecasting Americans’ long-term adoption of connected and autonomous vehicle technologies” from the University of Texas at Austin conducted an in-depth survey of consumers’ willingness to pay for individual automation tasks. This survey contained a variety of questions in regard to the respondents’ vehicle ownership history, vehicle preferences, and demographics. On top of this, the survey had respondents report their interest in and willingness to pay for individual pieces of automation technology as well as their aggregated willingness to pay to add level 3 and 4 automations. The data collected was then able to be used to run scenarios on AV adoption based on future increases in consumers’ willingness to pay and the cost reduction in AV technology.

For both level one and two automation technologies, the respondents expressed little willingness to pay for nearly all of these technologies. Roughly 30-50% of respondents were not willing to pay anything to add technologies such as electronic stability control, lane centering, left turn assist, adaptive cruise control, blind-spot monitoring, and emergency automatic breaking. For the consumers who did report a willingness to pay, the projected cost of these technologies in 5 years was greater than the average willingness to pay for all of the technologies except electronic stability control (Bansal & Kockelman, 2017). If price projections hold steady and consumers' willingness to pay remains the same, these results show little adoption of these technologies over the next five years.

Similar findings held true for level 3 and 4 automations. 55.4% of respondents expressed not wanting to pay anything for level 3 automation and 59.7% for level 4 automation. The averages of respondents willing to pay for these technologies were $5,470 and $14,196 respectively (Bansal & Kockelman, 2017). Again, this willingness to pay does not exceed current AV technology prices and limits adoption in the short run. However, researchers are quick to point out that the shortfalls in willingness to pay are likely are result of respondent's inability to conceive a world in which AVs are abundant and many are likely to have concerns about the technology's reliability until more information about AVs enters the public domain. Once consumers learn of the increased reliability and safety of autonomous vehicles, their willingness to pay will likely begin to increase as the technology costs begin to decrease (Bansal & Kockelman, 2017).

The study built out a transaction decision model for AV technologies to estimate over time each their adoption rates. The researchers inputted eight unique scenarios in to this model including those with annual increases in willingness to pay ranging from 0 to 10%, annual technology cost reduction rates of 5 to 10%, and government regulations. These models show that 98% of the US vehicle fleet will have electronic stability control by 2025 and vehicle connectivity by 2030 under expected NHTSA regulations. These regulations accelerate these technologies adoption rates by 15-20 years. Additionally, these models show that with at least a

10% annual increase in willingness to pay and a 10% annual decrease in prices all level one technologies will see 90% adoption rates by 2045. For more advanced automation levels the scenarios forecast a wide range of possibilities. Level four AV adoption in this model ranges from 24.8% by 2045 if current perceptions and willingness to pay remain the same and technology cost declines by 5% annually to 87.2% adoption if willingness to pay increases 10% annually and technology cost declines by 10% annually. Researchers are quick to note that willingness to pay could go a variety of directions in the future and it is possible that as the technology becomes proven it could increase by more than 10% a year. Or inversely, a well-publicized tragedy involving AVs could actually decrease future willingness to pay[4] (Bansal & Kockelman, 2017).

Diffusion Model Predictions

Similar to the Victoria Transport Policy Institute's study, the paper "Market Penetration Model for Autonomous Vehicles on the Basis of Earlier Technology Adoption Experience" out of Florida International University seeks to predict AV adoption based on previous technologies' adoption rates; however, this paper utilizes non-automobile related technologies and a more mathematical approach in its predictions.

This paper utilizes a generalized Bass diffusion model to predict the cumulative sales of AVs over time. The rationale behind the use of this model is that new product adoption typically follows an S-shaped curve where the slope at any given point on the curve is the new technology's adoption rate. This makes intuitive sense. New technology adoption typically starts

[4] On March 19th, 2018 an Uber AV killed a pedestrian. Initial investigations have revealed the incident was the pedestrians fault.

slow due to consumers lack of awareness of the product, but over time as awareness grows adoption increases until the product begins to reach market saturation and the adoption rate levels off to near zero. This adoption trend can be seen in figure 4 below where eventually the noncumulative adoption of a product will peak at a given point in time resulting in a tapering off of cumulative sales. Bass diffusion models run on the basis that adoption relies strictly on consumers being influenced by media or word of mouth in their purchasing decision. This means that the takeoff is a result of increased awareness of a product and its utility, not a decline in price over time, although that does happen with most products. For that reason, researchers utilized a generalized model so they could add the parameters of declining AV technology costs and increases in consumer wealth (Lavasani, Jin, & Du, 2016).

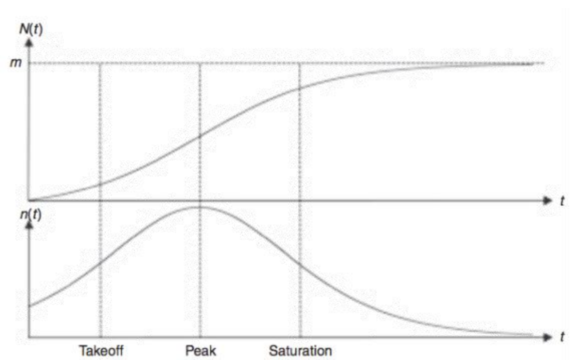

Figure 4. Bass model cumulative and noncumulative adopter curve (Lavasani et al., 2016)

In order for this study to predict AV market penetration using the Bass model, the researchers needed to select products with similar adoption patterns. To do this, researchers first selected the historical sales data of hybrid electric vehicles in the US. Hybrids were selected over other automobile technologies because hybrids saw relatively slow initial adoption due to skeptical users, similar to what is expected of AVs. However, the researchers also recognized that hybrids did not paint a complete picture of AV adoption since hybrids were not revolutionary in changing the way consumers interacted with vehicles. For that reason, the adoption of the internet and cell phones were also included in their model (Lavasani et al., 2016).

Cell phones and the internet specifically were used to estimate the market saturation of AVs placing it at 75% of US households. This meant that with roughly 115 million US households the market for AVs would be 87 million vehicles. Researchers also ran on the assumption that since AVs change the market substantially with possible ride sharing applications and reducing the demand for multiple vehicle households they did not consider multiple car households in this calculation (Lavasani et al., 2016).

With market size determined and historical data on the selected products adoption, researchers were able to buildout a generalized Bass model for AVs. They then were able to further analyze this model through two sensitivity analyses: one on the market size of AV and the other on AV technology cost. These sensitivity analyses showed that with a market introduction of AVs in 2025 it will take roughly 35 years for AVs to reach their market saturation at any level selected (Lavasani et al., 2016). However, the Bass model developed appears to have some issues with external variables where large increases in costs appear to not make substantial impacts on the adoption timeline as well as the lack of consideration behind different legislative issues.

Industry Predictions

Although typical industry reports on AV adoption are not as focused on the methodology behind the predictions like the previously discussed papers, they often receive just as much weight when it comes to investment decisions. Table 4 below contains the predictions of several of these reports gathered in the previously discussed paper "Forecasting Americans' long-term adoption of connected and autonomous vehicle technologies."

Table 4. Industry Reports (Bansal & Kockelman, 2017)

Source	Forecast
Lux Research	• 92% and 8% of world vehicles to have Level 2 and 3 automation in 2030 • Year 2030 revenues from Level 2 plus Level 3 sales: $21B for the U.S. and $20B for Europe
Morgan Stanley	• Nearly 100% of U.S. light-duty vehicles are Level 3 and 4 vehicles by 2030 and 2055, respectively • Cost to add Level 3 automation is forecasted to be $6000 per vehicle by 2030 and $10,000 for Level 4 by 2045
Fehr & Peers	• 25% of U.S. vehicle fleet to be autonomous by 2035
HIS Automotive	• Entire global fleet is expected to be to be fully-autonomous by 2050
IDTechEx	• The number of self-driving capable cars to reach 8.5 million by 2035 in the U.S.
BCG	• U.S. sales of level 4 AVs will reach about 10% of all new light-vehicle sales by 2035
Citi GPS	• Global market for level 4 AVs could reach $40 billion by 2025
ABI Research	• 50% of all new vehicle sales to be Level 4 AVs by 2032

It is clear from this table that there are a wide variety of industry forecasts out there that are both very conservative about AV adoption like Boston Consulting Group (BCG) and very bullish like Morgan Stanley. Ultimately, these estimates must factor in many of the variables considered in the larger academic studies such as consumer willingness to pay, the current and future cost of autonomous technology, and government regulations.

Summary and Consolidated Predictions

Throughout this breakdown of the different types of predictions, a variety of methods have been used to predict AV adoption resulting in no standard adoption prediction. However, across all of these reports several important things have remained fixed: AVs will be entering the market, AV technology is costly but costs will decline over time, consumers are hesitant to adopt this technology in the short run but eager to adopt in the long run, and the government has the ability to either accelerate AV adoption or to slow it down.

Out of all the predictions analyzed the Victoria Transport Policy paper continues to have the most encompassing prediction of AV adoption with both bearish and bullish estimates for each decade that closely align with the predictions seen in the other studies. For future modeling purposes, we can assume that there are two possible future cases for AV adoption: one with a government mandate and the other allowing AV to reach their natural adoption levels. With a government mandate we can assume that the market saturation of AVs will reach nearly 100% and without one we can assume the saturation will be near 80% based on other technologies such as cell phones and the internet. With that assumption made, we can utilize two data points for each of these cases from the studies and formulate an S-curve for each.

Model Methodology

The standard S-curve equation is represented by equation 1 below. In order to be able to transform the curve so that we can control for the speed of market adoption and the timing of growth, two additional parameters must be added: alpha and T_0, seen in equation 2. Alpha is responsible for stretching or compressing time and T_0 shifts the timeline of the curve

(Brandewindere, 2008). It is important to note that $f(t_i)$ is the percent of the market saturation achieved at that point in time not simply the percent of the market captured.

(1) $$f(x) = \frac{1}{1+e^{-x}}$$

(2) $$f(t) = \frac{1}{1+e^{-\alpha(t-T_0)}}$$

With our current predictions we have multiple points of both a date and the percent AV adoption in the market. Taking two of those pairings [converting market captured into percent of market saturation for $f(t_i)$] for both estimations for with and without a federal mandate, we can solve for alpha and T_0 such that $f(t_1) = f_1$ and $f(t_2) = f_2$. By formatting both of these equalities we can arrive at a solvable pair of linear equations (Brandewindere, 2008). The reformatting is shown in equations 3 through 6 for just f_1, however the process is the same for f_2.

(3) $$f(t_1) = f_1$$

(4) $$\frac{1}{1+e^{-\alpha(t_1-T_0)}} = f_1$$

(5) $$e^{-\alpha(t_1-T_0)} = \frac{1}{f_1} - 1$$

(6) $$-\alpha\ (t_1 - T_0) = \ln\left(\frac{1}{f_1} - 1\right)$$

The system of equations to be solved is represented by 7. By solving this system for both alpha and T_0, you would arrive at equations 8 and 9 (Brandewindere, 2008).

(7) $$\begin{cases} -\alpha\ (t_1 - T_0) = ln\ \left(\frac{1}{f_1} - 1\right) \\ -\alpha\ (t_2 - T_0) = ln\ \left(\frac{1}{f_2} - 1\right) \end{cases}$$

(8) $$\alpha = \frac{ln\ \left(\frac{1}{f_1} - 1\right) - ln\ \left(\frac{1}{f_2} - 1\right)}{t_2 - t_1}$$

(9) $$T_0 = \frac{ln\left(\frac{1}{f_1} - 1\right)}{\alpha} + t_1$$

Model Outputs

Applying these equations to the predictions gathered throughout the literature review allows us to create our own AV adoption models. Table 5 contains the two sets of predictions selected for adoption cases with and without a federal mandate. These numbers have been revised slightly upwards to reflect market saturation in terms of vehicle miles traveled since newer vehicles typically are driven more (Litman, 2017). These data points were plugged into equation 8 then 9 to arrive at the alpha and T_0 values shown. With these values calculated they could then be plugged into equation 2 to give us the formula for each case's adoption curve.

Table 5. Adoption Model Cases

	Without Mandate	**With Mandate**
Prediction 1 $(t_1, f(t_1))$	(2035, 10%)*	(2035, 15%)
Prediction 2 $(t_2, f(t_2))$	(2040, 35%)*	(2040, 50%)
Market Saturation	80%	100%
Alpha	.32	.35
T_0	2041.96	2040

*percentage of saturation value

Figure 5 plots the outputs of the two models for the years 2020 through 2060. Interestingly, both models start relatively similar to one another. This is because in the short run there is little the government is likely to do to further support the development and cost reduction of autonomous vehicles even in the mandate case. This closely mimics the adoption of both hybrid and all electric vehicles. The government has supported short term efforts with varying subsidies but ultimately that has been proven to have had little effect on substantially increasing adoption. The true difference comes from a federal mandate that all vehicles sold must be self-driving after a certain date (Litman, 2017). The mandate model created assumes an announcement of such mandate would come in the early 2030's and it would go into effect in the early 2040's. The announcement itself should motivate car manufactures to increase development and begin to enter large scale production of AVs thus boosting AV adoption prior to the mandate going into effect. Additionally, once the mandate does officially go into effect the 16+ million new car sales per year being entirely autonomous will quickly push AV to a 100% saturation level. The model without a mandate will likely follow an adoption pattered similar to what was seen in the Florida International study. Later with the use of these two models and an understanding of the increased safety of AV, we can begin to see how large of a positive economic impact that would stem from an aggressive government mandate.

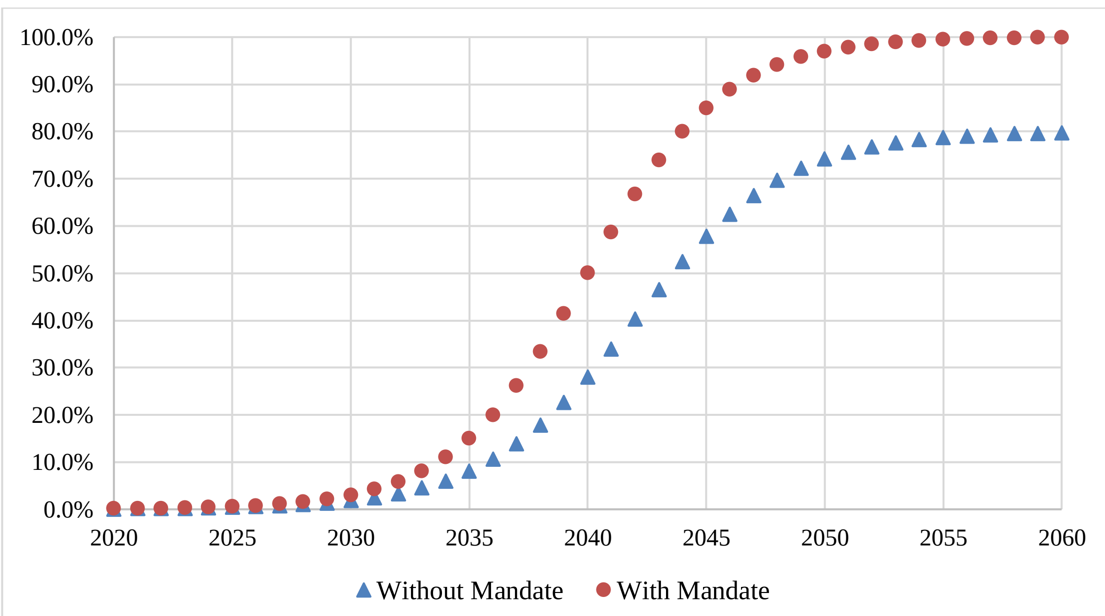

Figure 5. Adoption Models with and without a Federal Mandate

Chapter 4

Accident Rates

Introduction

Chapter 1 provided an overview of car safety over the last hundred years as well as a brief analysis of where car safety falls today. The largest takeaway is that car safety, specifically fatalities for 100 million vehicular miles traveled, has plateaued over the last three decades. Additionally, it was shown in a 2010 report that car crashes were responsible for $242 billion in economic costs and an additional $594 billion in societal costs. When working towards calculating the decreased economic and societal impact of a federal mandate for autonomous vehicles, it is necessary to develop a model that utilizes the outputs of each of the adoption models in calculating the number of car accidents for both. Several variables are needed to do this: accident rates for both autonomous and non-autonomous vehicles, total vehicle miles driven for each year, and the average cost per accident.

Accident Rates

The NHTSA focuses a bulk on their reporting on accidents that resulted in fatalities. This is because across the United States each State has its own unique definitions of what is classified as an accident and many accidents, especially those with only property damage, go unreported to both the police and insurance companies. For that reason, researchers typically adjust accident rates beyond the reported figures. However, the reported figures still are a great baseline when trying to determine accident rates. Table 6 shows the breakdown of all police reported accidents from 2010 to 2015. One of the larger takeaways from this table is that the composition of accidents has remained fairly stable. Roughly .5-.56% of accidents result in a fatality, 27-29% result in an injury, and the remaining 70-73% result in only property damage. Another key takeaway is that the total number of accidents has been increasing relative to the number of total miles driven. This has led to an increasing accident rate over this six-year period. In 2010, there was roughly 1.8 accidents for every million miles traveled and by 2016 it had increased to over 2 (National Center for Statistics and Analysis, 2017).

Table 6. 2010-2015 Police Reported Accident Breakdown and Accident Rates (National Center for Statistics and Analysis, 2017)

	Fatal		Injury		Property Damage Only		Total Accidents	Vehicle Miles Traveled (Millions)	Accident Rate (per million miles traveled)
Year	Number	Percent	Number	Percent	Number	Percent	Number	Total	
2010	30,296	0.56%	1,542,000	28.46%	3,847,000	70.99%	5,419,000	2,967,000	1.83
2011	29,867	0.56%	1,530,000	28.66%	3,778,000	70.78%	5,338,000	2,950,000	1.81
2012	31,006	0.55%	1,634,000	29.10%	3,950,000	70.35%	5,615,000	2,969,000	1.89
2013	30,202	0.53%	1,591,000	27.98%	4,066,000	71.50%	5,687,000	2,988,000	1.90
2014	30,056	0.50%	1,648,000	27.18%	4,387,000	72.34%	6,064,000	3,026,000	2.00
2015	32,166	0.51%	1,715,000	27.24%	4,548,000	72.24%	6,296,000	3,095,000	2.03

The 2010 NHTSA report “Economic and Societal Impact Of Motor Vehicle Crashes” calculated that approximately 60% of property-damage-only crashes go unreported and 24% of injury crashes go unreported (Blincoe et al., 2015). Table 7 revises the data in table 6 to include these estimates of unreported accidents. This not only resulted in substantial changes to the composition of accidents, but also more than doubled the accident rates.

Table 7. 2010-2015 Revised Accident Breakdown and Accident Rates

	Fatal		Injury		Property Damage Only		Total	Vehicle Miles Traveled (Millions)	Accident Rate (per million miles traveled)
Year	Number	Percent	Number	Percent	Number	Percent	Number	Total	
2010	30,296	0.26%	2,028,947	17.38%	9,617,500	82.36%	11,676,743	2,967,000	3.94
2011	29,867	0.26%	2,013,158	17.52%	9,445,000	82.22%	11,488,025	2,950,000	3.89
2012	31,006	0.26%	2,150,000	17.83%	9,875,000	81.91%	12,056,006	2,969,000	4.06
2013	30,202	0.25%	2,093,421	17.04%	10,165,000	82.72%	12,288,623	2,988,000	4.11
2014	30,056	0.23%	2,168,421	16.47%	10,967,500	83.30%	13,165,977	3,026,000	4.35
2015	32,166	0.24%	2,256,579	16.52%	11,370,000	83.24%	13,658,745	3,095,000	4.41

Although official figures have yet to be released it appears as though this trend has continued since 2015. The current estimate for fatalities in 2017 is 40,200 as reported by the National Safety Council, a nonprofit organization that works with auto-safety regulators. This increase is not simply a product of the increase in total miles traveled it is also largely contributed to more deaths per mile driven. Since this increase is relatively recent, there are a lack of studies on the driving forces behind it. However, data suggests a large component is increases in distracted driving. Hands free options in cars have failed to pull drivers away from utilizing social media sites and other applications that require they take their eyes off the road. This increase in distracted driving is also coupled with declines in police enforcement of speed limits, raising speed limits, and lax seatbelt laws/enforcement (Boudette, 2017).

To remain conservative for modeling purposes, I am going to utilize an average of the six revised accident rates which comes to 4.13 accidents per million miles driven. At this point in time, it is too early to determine if this trend will continue. Increased police enforcement and penalties or increases in non-autonomous technology may assist in bringing this rate back down or inversely increases to driver distractions may result in a higher rate.

Vehicular Human Error

The rising accident rates began to hint at how substantial human error is when it comes to car accidents. The foundational study on driver error titled “Tri-level study of the causes of traffic accidents” was commissioned by the Department of Transportation and carried out by the Institute for Research in Public Safety at Indiana University. Although released in 1979, this paper is still one of the most heavily cited sources when it comes to human error. The component of the study specifically focused on human error, dispatched teams of investigators directly to car crash scenes to interview the drivers involved as well as analyze the scene for any indications of human, vehicle, and environmental causes. In later stages of the study, researchers went as far as to test drivers vision and knowledge and later tow and analyze the vehicles in their own facilities. Furthermore, researchers used surveys and government reports to collect additional crash data to analyze. When investigating the accidents researchers sought to identify two types of factors causal and severity-increasing (Joscelyn & Treat, 1979). The exact definitions are given below.

- Causal Factors – a factor necessary or sufficient for the occurrence of the accident; had the factor not been present in the accident sequence, the accident would not have occurred.
- Severity-Increasing Factor – a factor which was neither necessary nor sufficient for the accident’s occurrence, but removal of which from the accident sequence would have lessened the speed of the impact which resulted (Joscelyn & Treat, 1979).

Through this analysis researchers found that in at least 70% of accidents human error or deficiencies were the direct cause and in 92 to 95% of accidents humans were the probable causes. The remaining portion of accidents was contributed to environmental causes and vehicle failure (Joscelyn & Treat, 1979). Although, common knowledge today this study was instrumental in revealing the faults of driver error.

More recently in 2008 the NHTSA conducted a similar study of crash causation. In this study, the NHTSA had teams positioned in select areas of the US to respond to car accidents to collect data prior to it being cleared. Over a two-and-a-half-year period they developed a sample of 5,471 crashes believed to be nationally representative. For each of the crashes, both the critical event that caused the accident and the critical reason for that event were documented. For 93% of the 5,471 crashes, the critical reason for critical pre-crash event was attributed to drivers (Singh, 2015). Table 8 shows which specific human contributed error to these specific instances. The NHTSA still relies heavily on this study to estimate the causes behind car crashes today.

In the context of exploring AVs' safety, this human error component is encouraging because presumably, since an AV would require no driver actions, it would not make these mistakes. Naturally, AVs may have their own sort of software and hardware failings that make up for some portion of increase safety in this area but presumably this large percentage leaves room for AV to be substantially safer.

Table 8. Critical Reason for Critical Pre-Crash Event Contributed to Drivers (“National Motor Vehicle,” 2008)

Critical Reason for Pre-Crash Event		Number of Crashes	Percentage
Recognition Error	Inadequate surveillance	1,080	21.19%
	Internal distraction	482	9.46%
	External distraction	229	4.49%
	Inattention	194	3.81%
	Other/unknown recognition error	109	2.14%
	Subtotal	2,094	41.09%
Decision Error	Too fast for conditions	348	6.83%
	Too fast for curve	181	3.55%
	False assumption of other's action	260	5.10%
	Illegal maneuver	232	4.55%
	Misjudgment of gap or other's speed	212	4.16%
	Following too closely	85	1.67%
	Aggressive driving behavior	99	1.94%
	Other/unknown decision error	335	6.57%
	Subtotal	1,752	34.38%
Performance Error	Overcompensation	211	4.14%
	Poor directional control	249	4.89%
	Other/unknown performance error	30	0.59%
	Panic/freezing	20	0.39%
	Subtotal	510	10.01%
Non-performance Error	Sleep, actually asleep	160	3.14%
	Heart attack or other physical impairment	133	2.61%
	Other/unknown critical nonperformance	76	1.49%
	Subtotal	369	7.24%
Other/unknown driver error		371	7.28%
Total		5,096	100.00%

Autonomous Vehicle Error

Federal regulations are likely to prevent mass market autonomous vehicles from being introduced until they are safer than human driven vehicles. This means that off the bat the crash rate of AV will be below the 4.13 average crash rate per million miles we are using for human driven vehicles. In addition, to the AV crash rate being lower, it is likely to improve over time with advances in autonomous software and hardware on new vehicles and the peer effects of having more AV on the road.

Current AVs show great promise in the area of offering increased vehicle safety. In partnership with Google, the Virginia Tech Transportation Institute completed a study comparing crash rates of vehicles today and Google's AV data. In this study, the researchers explored the accidents that occurred with Google's self-driving vehicles over the 1.3 million miles of driving completed in autonomous mode. Over the 1.3 million miles of driving, Google's vehicles experienced a raw crash rate of 8.7 accidents per million miles driven. This figure is higher than the nationally experienced crash rate; but, Google must report all incidents with their AVs unlike real car crash data and the composition of miles driven in Google's AVs does not match US averages. Researchers took Google's data and properly weighted it for crash severity and composition of miles driven and found that the true accident rate for Google's AVs would be 3.2 accidents per million miles driven (Blanco, Atwood, Russell, Trimble, McClafferty, & Perez, 2016). This figure is below both the 4.2 accidents per million miles driven crash rate for vehicles today calculated by the researchers and the 4.13 rate calculated in this paper. This again confirms that AVs will be in a developmental position to enter the market by 2020 and that they will offer increased safety.

There are two issues with utilizing just the Virginia Tech study when estimating the increased safety of AV. The first is that it used a limited sample size of miles driven. When it comes to today's crash rate of over 4 accidents per million miles traveled it is backed by observations over trillions of miles whereas the Google AV rate is backed by just over 1 million miles. Secondly, the Virginia Tech study utilized data from Google's self-driving car project from 2015. Although 2015 is fairly recent, the five-year spread from the collection of this data and the introduction of AV in the market represents a substantial amount of time for further development in AV safety. For these reasons, it is important to also factor in more theoretical predications of expected AV safety.

In 2014, the Casualty Actuarial Society Automated Vehicles Task Force analyzed the previously discussed NHTSA crash causation report. The goal of the report was to reanalyze the data in the context of AV to affirm or deny whether AV have the ability to prevent the 93% of accidents caused by human error. Researchers looked into each of the 5,471 crashes to determine if autonomous technology could have prevented them. In doing so, researchers "found that 49% of accidents contain at least one limiting factor that could disable the technology or reduce its effectiveness ("*Restating the National Highway*," 2014)." Inversely this means that the researchers believe that AVs would be at least 51% as dangerous as vehicles today. It is also important to note that the 49% of cases identified had limiting factors that *could* disable or reduce the technology's effective not necessarily *would* have. This means that AV are likely even less dangerous than the 51% effectiveness. In addition to this, the Casualty Actuarial Society conducted this study in 2014 where their vision for AVs was a car that could be both be human driven as well as self-driven. As a result, there were more cases in which passengers in the vehicle could have accidentally caused accidents by disabling the AV technologies. Under today's impression that a bulk of future ATVs will not provide typical human driven options it is likely the 49% figure would be lower.

Lastly, researchers from the University of Utah and University of Texas at Austin aggregated various AV safety predictions in their paper "Preparing a nation for autonomous vehicles: opportunities, barriers and policy recommendations." This paper explored a variety of different safety implications of AV including similar issues with human error as discussed previously. However, the paper was also quick to point out situations in which human drivers may act more appropriately than AVs. For example, a human driver would be able to react differently if a cardboard box or boulder suddenly rolled in front of their car as they were driving down the highway, whereas an AV would struggle to identify the objects composition and thus treat both as the same. This means where a human driver may drive safely through a cardboard box an AV might make a dangerous deceleration. On top of these current limitations of AVs, the paper also discusses the predictability of other drivers. The more AVs on the road, the more likely an AV will be able to predict the behavior of the vehicles around it. With few AVs on the road initially, the technology will be less likely to predict drivers behaviors and as a result will be less safe than they will be with higher adoption rates. Lastly, is evolving technology. AVs will have the ability to improve overtime. This can happen as advancements in both autonomous software and hardware occur. New AVs will have the benefit of newer and more accurate sensors and cameras, while older AVs still have the ability to perform better via software updates. For these reasons, the paper predicted that at a 10% adoption rate AVs will be 50% safer and at a 90% adoption rate AVs will be 90% safer (Fagnant & Kockelman, 2015).

This last prediction by Fagnant and Kockelman, appears to be the most encompassing of the three papers explored. The predication is not overly ambitious with early AV safety, but also demonstrates a more current view of AVs with its long-term predictions. For these reasons, it would be best to use their prediction in our model. The prediction is simplified into three formulas shown in table 9. These formulas assume that increases in AV peer effects as well as technological advancements will be linear for simplicity. Additionally, we are assuming there are no further safety gains after 90% adoption in order to be conservative.

Table 9. AV Crash Rate Reduction Formulas

Condition	Formula for % Crash Rate Reduction
AV adoption is less than 10%	= 5 (AV Adoption %)
AV adoption greater than 10% and less than 90%	= 50% (AV Adoption %) + 45%
AV adoption greater than 90%	= 90%

The outputs of the previously calculated AV adoption models can be inputted into these formulas to determine how much safer AVs are compared to human driven vehicles for each year. We can then multiply our human driven accident rate by (1-% Crash Rate Reduction) to get the yearly AV accident rates.

Chapter 5

Projected Vehicle Miles Driven

Introduction

The last remaining component of the model needed is the forecasted vehicular miles traveled (VMT) over our adoption model's timeframe. Since the accident rates are based on total miles driven in the U.S., the projected VMT can be divided based on AV adoption rates and then divided by the respective crash rates for autonomous and non-autonomous vehicles to get the total number of crashes. To best be able to predict how many miles will be driven in the U.S. over the next 50 years, it is beneficial to look at both the historical growth of miles driven as well as the factors that may impact future growth.

Historical Growth

Figure 6 graphs the total annual VMT in the U.S. since 1970 as reported by the US Federal Highway Administration. Over the 48-year period shown, the total VMT has increased by 186%. The linear trend line reveals that the growth experienced year over year has been fairly consistent with minor deviations above the line in periods of high economic growth and deviations below the line during economic recessions. Most recently during the 2007/08 financial crisis we saw declines in the total VMT that have just recently rebounded above the levels experienced prior. Although, slight deviations away from a linear growth occurred over the period of time shown, a compound annual growth rate of 2.22% represents the trend seen fairly consistently.

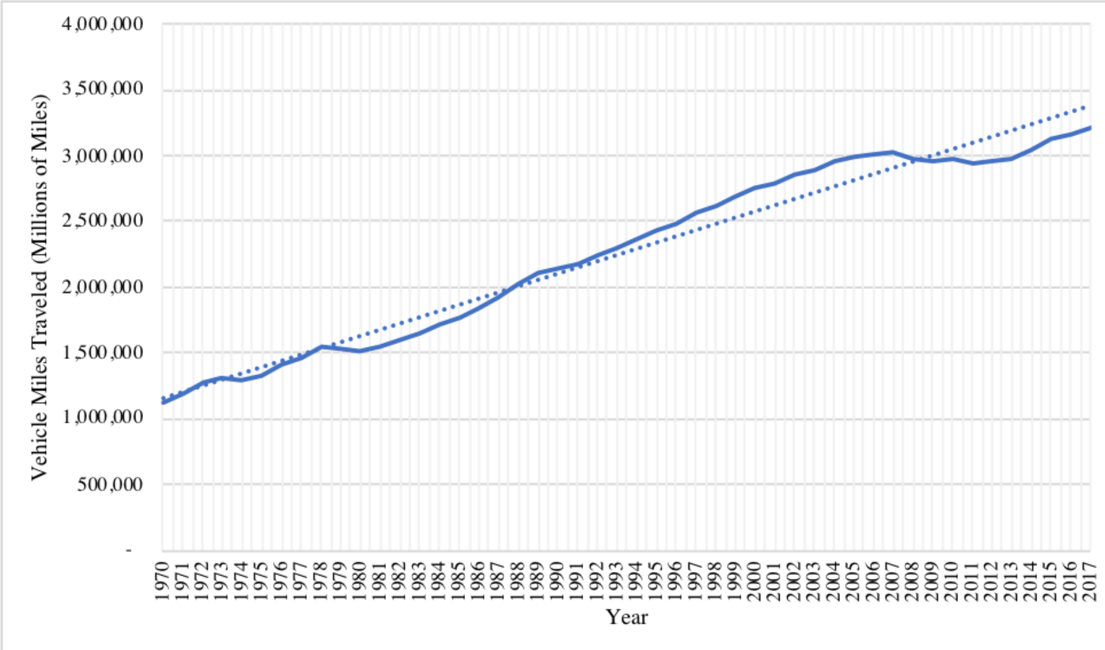

Figure 6. Total US Vehicular Miles Traveled (U.S. Federal Highway Administration, 2018)

Although the 2.22% annual growth has been experienced fairly consistently over the entire period, the way in which the VMT has grown since the initial declines in 2007/08 paint a different story of what the future growth may be. In 2011, the declines in total VMT bottomed out and since the total VMT has been increasing on average by 1.44% annually. This average is also skewed by 2.04% and 2.95% increases experienced in 2014 and 2015 respectively. The growth for 2016 and 2017 was closer to 1.2%. As a result of the growth not returning to the typical yearly average, it is worthwhile to look for something better to base future projections off of.

Government Predictions

The Federal Highway Administration (FHWA) released its most recent outlook of total VMT in May 2017. This report focused on forecasting VMT through 2045 based on the economic outlook of the United States. To do this the FHWA relied on a report by Information Handling Services (HIS), a company that provides information and analysis to allow governments and companies make better decisions.

The FHWA specifically focused on five economic and demographic indicators: U.S. population, GDP, real goods component of GDP, disposable income per capita, and gasoline price per gallon. Table 10 displays both the historical growth across these five indicators as well as the IHS's forecasts. The first four listed in the table have lower forecasted growth rates than have been experienced in the past all of which would likely result in less growth in VMT. The last factor of gasoline price increasing at a lower rate would have a slight impact on increasing miles traveled; however, the decline is minimal and the impact is lessened due to the rise of alternative fuel sources and higher miles per gallon.

Table 10. IHS Long-Term Economic Forecasts (U.S. Federal Highway Administration, 2017)

Demographic and Economic Indicators	Historical Growth Rate (1966 to 2015)	Forecast Growth Rate (2015 to 2045)
U.S. Population	1.01%	0.63%
GDP (Real 2009$)	2.80%	2.06%
Real Goods Component of GDP (Real 2009$)	3.21%	2.89%
Disposable Personal Income per Capita (Real 2009$)	1.97%	1.67%
Gasoline Price per Gallon (Real 2009$)	0.65%	0.63%

In the forecast report, the FHWA does not elaborate on its exact process of analyzing and weighing the above five variables to achieve their forecasted VMT but their forecasts do align with the trend of less growth. From 2015 to 2045 the compound annual growth rate of VMT is forecasted to be 0.78%. They also generated pessimistic and optimistic forecasts that are 0.66% and 0.89% respectively.

The RAND Corporation pointed out in their paper, “The Enemy of Good: Estimating the Cost of Waiting for Nearly Perfect Automated Vehicles,” that there is a lot of uncertainty surrounding VMT forecasts. Specifically, they discussed how substantially the FHWA’s forecasts changed from 2016 to 2017. In 2016, the FHWA’s 30-year forecasts ranged from 0.53% to 0.65% meaning that the upper bound in their 2016 forecast was lower than the lower bound in the 2017 forecast. Additionally, the researchers looked at the Energy Information Administration’s forecasts that go to 2050 and found similar levels of variation with their estimates over the last decade ranging from 0.7% to 1.8% annual VMT increases (Kalra & Groves, 2017).

Final Predication

When determining which compound annual growth rate to use for our model there are two issues with the current forecasts. The first issue is the uncertainty surrounding the current projections, to get around this we will utilize three growth cases: base, bear, and bull. This will allow us to have a range of possible impact with greater certainty rather than a singular estimate. The second issue is that the current forecasts at the furthest forecast the growth to 2050. In order to best represent the impact of a federal mandate, our model needs to go out to a minimum of

2060 since that is when the adoption rates begin to approach their saturation levels. To do this we could either revise down the entire growth rate down by the impact of the additional 15 years or we could select a new growth rate to apply following 2045. Both methods would arrive at the same 2060 figure but the latter method would lead to more accurate car crash figures for the earlier years.

Table 11. Vehicle Miles Traveled Compound Annual Growth Cases

Time Period	Bear	Base	Bull
2020 to 2045	0.53%	0.70%	0.89%
2045 to 2060	0.20%	0.30%	0.40%

Table 11 shows the three cases generated for the model. They are based on the 2016 and 2017 FHWA forecasts. The bear estimate contains the lowest estimate from the two reports, the base estimate is the average of the two years base forecasts, and the bull is the highest estimate of the two reports. The growth rates for 2045 and beyond were selected based on where the Energy Information Administration's expectations of the growth rate fall with the bull representing the full estimate and the base being revised down by 25% and the bear being revised down by 50%.

Chapter 6

Consolidated Model

Model Overview

Chapters 2 through 5 focused on gathering the necessary inputs to calculate the future economic and societal costs of car accidents. Figure 7 shows how each of these variables flow together in order to calculate the present value of the economic and societal costs associated with a given year's car accidents.

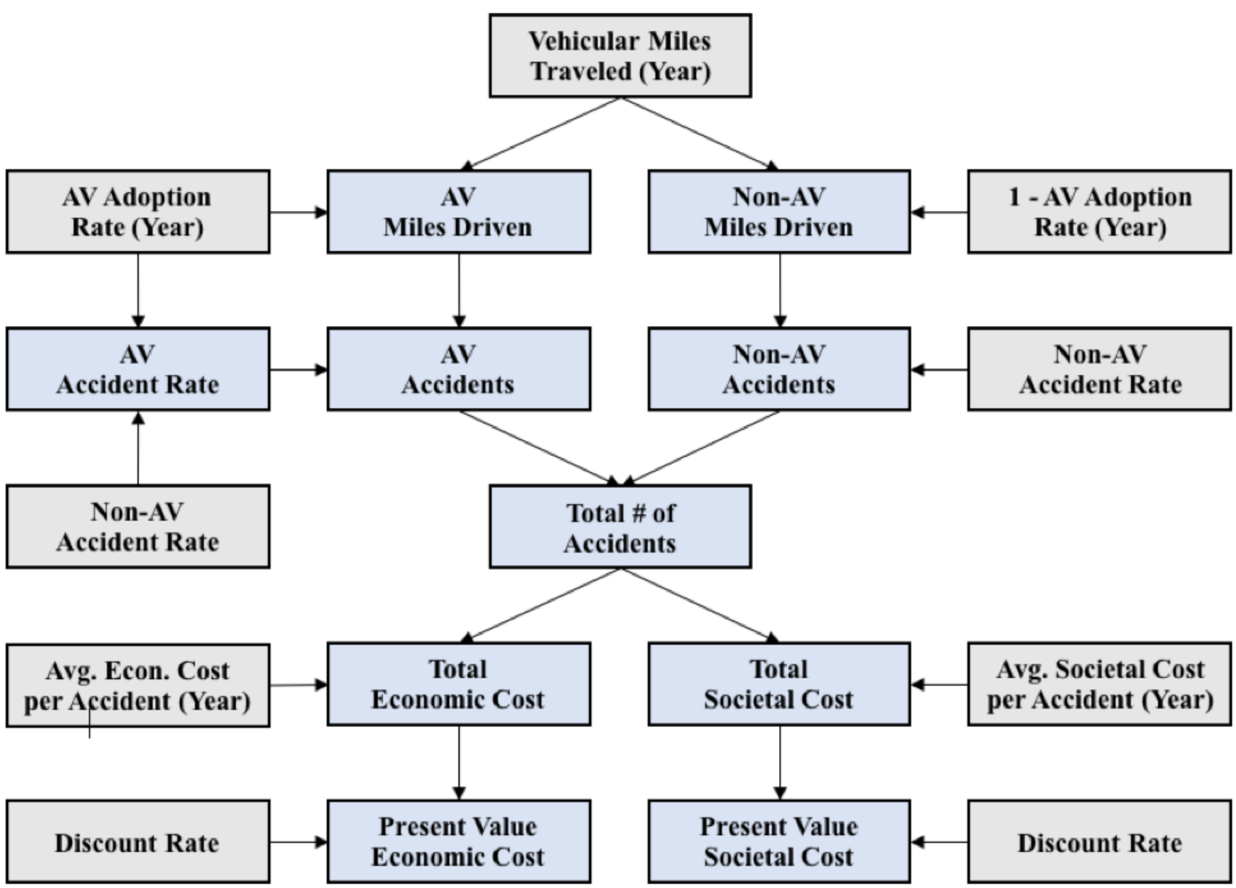

Figure 7. Model Inputs and Outputs (yearly)

Model Steps:

1. For each year in the period of 2020 to 2060, take the projected VMT and divide it into miles driven by AVs and miles driven by non-AVs using each years AV adoption rate.
2. Multiply miles driven by AVs and non-AVs by the corresponding accident rates for each.
    a. The AV accident rate for each year is calculated utilizing the year's AV adoption rate (see chapter 4).
3. Sum total accidents by AVs and non-AVs.
4. Multiply each year's total accidents by the forecasted average economic and societal cost per accident for that year.
5. Discount the costs back to the current year.
6. Sum all costs for the years 2020-2060.
7. Complete this process with the AV adoption models with and without a federal mandate for all three VMT cases.
8. Calculate difference between the outputs to determine the effectiveness of the mandate in reducing total accidents and costs.

Discount Rate

For this analysis, a yearly discount rate of 3% was used. Although this rate may seem low compared to the higher market return rates often used in a business context, it is actually conservative compared to the current federal discounting guidelines.

Since 1992, the Office of Management and Budget within the Executive Office of the President has issued yearly updates to its original report "Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs." These yearly updates include the discount rates that should be used when conducting cost-benefit and economic analyses. The discount rates are modeled off of the nominal interest rates of treasury notes and bonds for each maturity. Since this model exceeds 30 years, we would use the 30-year treasury rate which for 2018 is 2.6% (Office of Management and Budget, 2018).

To be both conservative and to mimic the discount rates in the NHTSA report "The economic impact of motor vehicle crashes" which the economic and social costs are modeled after, a 3% rate was selected for this model.

Model Outputs

The model was run for all three VMT forecasts with and without a federal AV mandate. A summary of the aggregate outputs for each case is in shown in table 12. The full models with yearly outputs are included in appendixes A through F.

From all of the model outputs, it is clear that a federal mandate would have a substantial impact on reducing the total number of car accidents as well as economic and societal costs. Specifically, a federal AV mandate could reduce the total number of car accidents over the 40-year period by 90 to 100 million. If the percentage of accidents that result in fatalities holds at 0.25%, this reduction could save 225,000 to 250,000 lives. The total economic cost of car accidents could be reduced by $1.6 to 1.8 trillion. The additional societal cost could be upwards of $3.9 to 4.4 trillion. In our most likely base case, all together the mandate would result in $5.9 trillion in total cost reductions.

Table 12. Key Model Outputs (all numbers in millions)

		Total Accidents	PV Economic Costs	PV Societal Costs	Total Costs
		Without Mandate			
VMT Cases	Bear	429.43	$8,287,333	$20,392,426	$28,679,759
	Base	443.12	$8,542,748	$21,020,918	$29,563,666
	Bull	458.97	$8,838,244	$21,748,038	$30,586,282
		With Mandate			
	Bear	338.64	$6,664,826	$16,399,964	$23,064,790
	Base	347.67	$6,837,441	$16,824,715	$23,662,156
	Bull	358.08	$7,036,432	$17,314,366	$24,350,798
		Difference			
	Bear	90.79	$1,622,507	$3,992,461	$5,614,969
	Base	95.45	$1,705,307	$4,196,204	$5,901,510
	Bull	100.89	$1,801,812	$4,433,672	$6,235,484

The model outputs paint a positive picture of what an AV mandate could do for the U.S.; however, the model has its limitations and an AV mandate may come with other unexplored costs that are worth considering.

Model Limitations

Similar to any model that attempts to calculate the benefit of a complex decision, the quality of the outputs from this model are contingent upon the quality of its inputs. Currently, the model utilizes the most current data and studies available to make the best prediction of what these variables will be; yet, ultimately these are simply best guesses on what these inputs will be and they could change substantially over time. Table 13 briefly discusses the limitations of each inputs' current assumptions. The key takeaway of the table is that none of the inputs are certain and should be adjusted to receive more accurate model outputs as we move closer to complete information.

Table 13. Model Input Limitations

Input	Limitation
Vehicle Miles Traveled (VMT)	As discussed, there is currently a large variety in yearly forecasts. Large changes in projected population or GDP growth could change the rates substantially. Additional large-scale transportation or infrastructure projects could have similar impacts. Also, forecasts do not explore increased miles traveled as a result of AV technology (i.e. someone living further from work because they can now be productive during their commute).
AV Adoption Rate	The developed AV adoption models used are contingent upon the government continuing to provide support for AVs as well as car companies meeting the development timelines currently announced. Either of these things could change over the next few years. Additionally, we assumed miles driven is split evenly by AV adoption rate. It is possible, especially in later years, that AV represent an even greater percentage of miles driven. Inversely, in earlier years the same could be said about non-AVs.
Federal Mandate	Model assumes mandate is announced in 2030 and goes into effect in early 2040's. This could be adjusted to explore the effectiveness of different timing.
AV Accident Rate	Model makes best assumption under limited AV data today was well as studies on human error. As increasing amounts of AV accident data is made available, the model's crash rates can be made more accurate.
Non-AV Accident Rate	Model assumes rate will hold stable at average of recent years. Increases or decreases could be seen with new technology, police enforcement, traffic laws, and driver distraction.
Average Economic/Societal Costs	Assumes that costs will continue to grow at rate seen from 2000-2010. Costs include property damage, healthcare, lost productivity, etc. all factors that could see increasing or decreasing growth. Additionally, the model assumes AVs get in same ratio of crash severity as non-AVs today. If AVs end up getting into less fatal accidents as cars today, the model would need to revise down average costs to match this.
Discount Rate	Model uses rate similar to government requirement. Rates have been declining in recent years due to low yields on treasuries. The rate could continue to decline or increase if economy picks up.

Next Steps

The goal of this paper was to evaluate the use of a Federal mandate for AVs in reducing both the economic and societal costs of car accidents. In doing so, the model developed has predicted that that a federal mandate can help reduce these costs by trillions of dollars over four decades while saving hundreds of thousands of lives. This output is extremely encouraging in showing how positive a mandate may be for the safety of our roads.

Nevertheless, it is important for these cost savings to be weighed against some of the costs associated with AVs. Specifically, it would be worthwhile to look into the impact of the adopted acceleration of AVs on job loss. There have been estimates that AVs have the ability to impact upwards of 10% of U.S. jobs. With a federal mandate both increasing the adoption timeline and market saturation levels of AVs, it would reduce the amount of time and increase how substantially the economy has to adapt. The way in which the economy responds to such a fast and substantial change could possibly result in a greater negative impact than the reduction in car accidents and for that reason is a critical factor that must be explored before a recommendation for a AV mandate can be made.

In addition to further analysis of the negative effects of such a policy, the U.S. is at least 2 years out from AVs being introduced to the market and decades away from a possible mandate. This leaves a large amount of time to further refine the model and its inputs to best forecast the savings from a mandate.

Appendix A

Full Model: VMT Base Case with AV Mandate

Year	Vehicle Miles Traveled (Millions)	AV Adoption	Non-AV Miles Driven	AV Miles Driven	Non-AV Crash Rate (per million miles)	AV Crash Rate (per million miles)	Non-AV Accidents	AV Accidents	Total Accidents	Average Economic Cost per Accident	Average Societal Cost per Accident	Economic Cost	PV Economic Cost	Societal Cost	PV Societal Cost	Total PV Costs
2020	3,276,369	0.10%	3,273,194	3,174	4.13	4.11	13,518,292	13,047	13,531,339	$22,520	$55,415	$304,727,763,367	$287,235,143,149	$749,835,732,330	$706,792,093,816	$994,027,236,965
2021	3,299,303	0.14%	3,294,783	4,520	4.13	4.10	13,607,453	18,542	13,625,994	$23,056	$56,734	$314,162,671,879	$287,503,348,850	$773,051,967,882	$707,452,060,654	$994,955,409,504
2022	3,322,398	0.19%	3,315,962	6,436	4.13	4.09	13,694,923	26,324	13,721,248	$23,605	$58,084	$323,888,184,236	$287,770,456,667	$796,983,284,806	$708,109,325,955	$995,879,782,622
2023	3,345,655	0.27%	3,336,493	9,162	4.13	4.07	13,779,718	37,320	13,817,037	$24,167	$59,466	$333,911,645,748	$288,035,118,830	$821,647,757,514	$708,760,573,301	$996,795,692,131
2024	3,369,075	0.39%	3,356,038	13,037	4.13	4.05	13,860,436	52,801	13,913,237	$24,742	$60,882	$344,238,886,980	$288,294,648,384	$847,059,733,130	$709,399,190,967	$997,693,839,351
2025	3,392,658	0.55%	3,374,115	18,543	4.13	4.02	13,935,096	74,489	14,009,586	$25,331	$62,331	$354,872,355,214	$288,543,699,635	$873,225,233,615	$710,012,024,943	$998,555,724,578
2026	3,416,407	0.77%	3,390,050	26,357	4.13	3.97	14,000,908	104,654	14,105,561	$25,934	$63,814	$365,807,309,449	$288,771,668,058	$900,132,592,913	$710,572,980,953	$999,344,649,011
2027	3,440,322	1.09%	3,402,894	37,428	4.13	3.91	14,053,951	146,169	14,200,120	$26,551	$65,333	$377,024,130,727	$288,957,602,287	$927,733,535,160	$711,030,504,503	$999,988,106,789
2028	3,464,404	1.53%	3,411,323	53,081	4.13	3.81	14,088,765	202,429	14,291,194	$27,183	$66,888	$388,472,932,465	$289,060,345,149	$955,905,305,728	$711,283,321,210	$1,000,343,666,359
2029	3,488,655	2.15%	3,413,513	75,142	4.13	3.69	14,097,809	276,914	14,374,723	$27,830	$68,480	$400,043,169,315	$288,999,697,071	$984,375,888,540	$711,134,086,052	$1,000,133,783,124
2030	3,513,075	3.02%	3,406,976	106,100	4.13	3.51	14,070,810	372,021	14,442,831	$28,492	$70,109	$411,504,741,951	$288,621,146,608	$1,012,579,084,127	$710,202,596,711	$998,823,743,319
2031	3,537,667	4.22%	3,388,386	149,281	4.13	3.26	13,994,036	486,449	14,480,484	$29,170	$71,778	$422,396,901,219	$287,631,735,894	$1,039,381,138,954	$707,767,979,334	$995,399,715,228
2032	3,562,431	5.87%	3,353,422	209,008	4.13	2.92	13,849,633	609,983	14,459,616	$29,864	$73,486	$431,826,724,842	$285,488,336,821	$1,062,584,862,251	$702,493,772,627	$987,982,109,448
2033	3,587,368	8.10%	3,296,685	290,682	4.13	2.46	13,615,310	714,132	14,329,441	$30,575	$75,235	$438,124,095,529	$281,215,185,158	$1,078,080,639,560	$691,978,938,759	$973,194,123,917
2034	3,612,479	11.09%	3,211,834	400,645	4.13	2.04	13,264,874	818,309	14,083,184	$31,303	$77,026	$440,842,901,309	$274,718,721,486	$1,084,770,734,682	$675,993,258,487	$950,711,979,973
2035	3,637,766	15.00%	3,092,101	545,665	4.13	1.96	12,770,379	1,070,458	13,840,837	$32,048	$78,859	$443,568,298,472	$268,366,115,431	$1,091,477,049,049	$660,361,564,937	$928,727,680,367
2036	3,663,231	19.98%	2,931,397	731,834	4.13	1.86	12,106,669	1,360,448	13,467,118	$32,811	$80,736	$441,863,285,141	$259,548,110,996	$1,087,281,566,808	$638,663,329,304	$898,211,440,299
2037	3,688,873	26.10%	2,726,065	962,808	4.13	1.73	11,258,650	1,668,092	12,926,742	$33,591	$82,658	$434,227,653,697	$247,633,963,358	$1,068,492,765,838	$609,346,494,107	$856,980,457,465
2038	3,714,696	33.32%	2,477,036	1,237,660	4.13	1.58	10,230,158	1,959,815	12,189,973	$34,391	$84,625	$419,224,126,471	$232,114,234,397	$1,031,573,974,127	$571,157,498,123	$803,271,732,521
2039	3,740,698	41.41%	2,191,565	1,549,133	4.13	1.42	9,051,163	2,194,073	11,245,236	$35,209	$86,639	$395,938,029,304	$212,836,200,957	$974,274,476,603	$523,720,539,435	$736,556,740,392
2040	3,766,883	50.00%	1,883,442	1,883,442	4.13	1.24	7,778,614	2,333,584	10,112,198	$36,047	$88,701	$364,518,298,552	$190,239,366,449	$896,960,757,111	$468,117,092,722	$658,356,459,171
2041	3,793,251	58.59%	1,570,897	2,222,354	4.13	1.06	6,487,805	2,359,423	8,847,229	$36,905	$90,812	$326,509,734,462	$165,439,788,234	$803,434,065,698	$407,093,411,497	$572,533,199,730
2042	3,819,804	66.68%	1,272,680	2,547,125	4.13	0.89	5,256,167	2,278,442	7,534,609	$37,784	$92,973	$284,685,091,489	$140,046,200,736	$700,517,247,597	$344,608,066,981	$484,654,267,717
2043	3,846,543	73.90%	1,003,960	2,842,583	4.13	0.75	4,146,356	2,119,065	6,265,421	$38,683	$95,186	$242,364,703,463	$115,754,732,166	$596,380,562,454	$284,834,678,027	$400,589,410,194
2044	3,873,469	80.02%	773,835	3,099,634	4.13	0.62	3,195,938	1,918,804	5,114,742	$39,604	$97,451	$202,561,992,636	$93,926,927,965	$498,439,060,530	$231,123,564,317	$325,050,492,282
2045	3,900,583	85.00%	585,087	3,315,496	4.13	0.52	2,416,411	1,711,625	4,128,036	$40,546	$99,771	$167,375,863,560	$75,350,781,974	$411,857,462,018	$185,413,721,936	$260,764,503,910
2046	3,912,285	88.91%	433,895	3,478,389	4.13	0.44	1,791,988	1,514,910	3,306,898	$41,511	$102,145	$137,273,062,822	$59,998,864,596	$337,784,278,181	$147,637,655,579	$207,636,520,176
2047	3,924,022	91.90%	317,961	3,606,060	4.13	0.41	1,313,180	1,489,303	2,802,483	$42,499	$104,576	$119,102,979,333	$50,540,916,019	$293,073,623,303	$124,364,725,935	$174,905,641,954
2048	3,935,794	94.13%	230,914	3,704,880	4.13	0.41	953,674	1,530,115	2,483,789	$43,511	$107,065	$108,071,085,776	$44,523,856,426	$265,927,727,922	$109,558,702,892	$154,082,559,318
2049	3,947,601	95.78%	166,579	3,781,022	4.13	0.41	687,970	1,561,562	2,249,532	$44,546	$109,613	$100,207,932,491	$40,081,884,839	$246,579,069,837	$98,628,458,200	$138,710,343,040
2050	3,959,444	96.98%	119,581	3,839,863	4.13	0.41	493,868	1,585,864	2,079,731	$45,606	$112,222	$94,848,877,103	$36,833,331,625	$233,392,180,736	$90,634,827,258	$127,468,158,883
2051	3,971,322	97.85%	85,538	3,885,784	4.13	0.41	353,271	1,604,829	1,958,100	$46,692	$114,893	$91,427,106,545	$34,470,418,831	$224,972,318,353	$84,820,468,808	$119,290,887,639
2052	3,983,236	98.47%	61,030	3,922,206	4.13	0.41	252,054	1,619,871	1,871,925	$47,803	$117,628	$89,483,670,248	$32,755,041,105	$220,190,154,880	$80,599,483,167	$113,354,524,272
2053	3,995,186	98.91%	43,464	3,951,721	4.13	0.41	179,508	1,632,061	1,811,569	$48,941	$120,427	$88,659,506,530	$31,508,116,679	$218,162,156,517	$77,531,208,456	$109,039,325,135
2054	4,007,171	99.23%	30,914	3,976,257	4.13	0.41	127,675	1,642,194	1,769,870	$50,106	$123,293	$88,680,223,877	$30,597,552,699	$218,213,135,158	$75,290,607,203	$105,888,159,901
2055	4,019,193	99.45%	21,967	3,997,226	4.13	0.41	90,725	1,650,854	1,741,579	$51,298	$126,228	$89,339,557,881	$29,927,227,485	$219,835,541,302	$73,641,155,271	$103,568,382,755
2056	4,031,250	99.61%	15,599	4,015,651	4.13	0.41	64,425	1,658,464	1,722,889	$52,519	$129,232	$90,484,283,156	$29,427,855,261	$222,652,337,204	$72,412,362,947	$101,840,218,208
2057	4,043,344	99.73%	11,072	4,032,272	4.13	0.41	45,728	1,665,328	1,711,057	$53,769	$132,308	$92,001,580,975	$29,049,825,430	$226,385,912,735	$71,482,154,710	$100,531,980,140
2058	4,055,474	99.81%	7,856	4,047,618	4.13	0.41	32,447	1,671,666	1,704,113	$55,049	$135,457	$93,808,969,854	$28,757,781,435	$230,833,307,842	$70,763,529,597	$99,521,311,032
2059	4,067,641	99.86%	5,573	4,062,068	4.13	0.41	23,017	1,677,634	1,700,651	$56,359	$138,680	$95,846,520,725	$28,526,608,342	$235,847,056,614	$70,194,687,943	$98,721,296,285
2060	4,079,844	99.90%	3,953	4,075,891	4.13	0.41	16,325	1,683,343	1,699,668	$57,700	$141,981	$98,070,957,003	$28,338,507,636	$241,320,669,480	$69,731,833,395	$98,070,341,031
						TOTALS	**298,556,181**	**49,115,411**	**347,671,591**	**-**	**-**	**$10,851,987,805,793**	**$6,837,441,065,117**	**$26,703,205,949,085**	**$16,824,714,531,019**	**$23,662,155,596,136**

Appendix B

Full Model: VMT Base Case without AV Mandate

Note: Since the non-AV crash rate, average economic cost per accident, and average societal cost per accident columns are the same for all models to conserve space they are not shown. Refer to appendix A to see figures used.

Year	Vehicle Miles Traveled (Millions)	AV Adoption	Non-AV Miles Driven	AV Miles Driven	AV Crash Rate (per million miles)	Non-AV Accidents	AV Accidents	Total Accidents	Economic Cost	PV Economic Cost	Societal Cost	PV Societal Cost	Total PV Costs
2020	3,276,369	0.08%	3,273,812	2,556	4.11	13,520,845	10,517	13,531,361	$304,728,266,072	$287,235,616,997	$749,836,969,324	$706,793,259,802	$994,028,876,800
2021	3,299,303	0.11%	3,295,775	3,528	4.11	13,611,550	14,494	13,626,044	$314,163,824,152	$287,504,403,343	$773,054,803,250	$707,454,655,417	$994,959,058,760
2022	3,322,398	0.15%	3,317,529	4,869	4.10	13,701,395	19,963	13,721,358	$323,890,783,159	$287,772,765,776	$796,989,679,908	$708,115,007,921	$995,887,773,697
2023	3,345,655	0.20%	3,338,936	6,719	4.09	13,789,807	27,470	13,817,277	$333,917,432,626	$288,040,110,642	$821,661,997,135	$708,772,856,523	$996,812,967,165
2024	3,369,075	0.28%	3,359,807	9,268	4.07	13,876,001	37,751	13,913,752	$344,251,635,723	$288,305,325,256	$847,091,103,633	$709,425,463,270	$997,730,788,525
2025	3,392,658	0.38%	3,379,878	12,780	4.05	13,958,895	51,789	14,010,684	$354,900,184,655	$288,566,327,517	$873,293,712,802	$710,067,704,789	$998,634,032,306
2026	3,416,407	0.52%	3,398,791	17,615	4.02	14,037,008	70,876	14,107,885	$365,867,559,145	$288,819,229,725	$900,280,847,783	$710,690,014,716	$999,509,244,441
2027	3,440,322	0.71%	3,416,058	24,264	3.98	14,108,317	96,677	14,204,995	$377,153,553,326	$289,056,793,932	$928,052,002,005	$711,274,582,822	$1,000,331,376,754
2028	3,464,404	0.96%	3,431,011	33,393	3.93	14,170,075	131,266	14,301,342	$388,748,775,598	$289,265,598,346	$956,584,065,797	$711,788,382,447	$1,001,053,980,793
2029	3,488,655	1.32%	3,442,753	45,901	3.86	14,218,571	177,102	14,395,673	$400,626,197,255	$289,420,888,860	$985,810,530,324	$712,170,501,801	$1,001,591,390,661
2030	3,513,075	1.79%	3,450,082	62,993	3.76	14,248,840	236,837	14,485,676	$412,725,480,865	$289,477,348,322	$1,015,582,924,826	$712,309,430,141	$1,001,786,778,463
2031	3,537,667	2.44%	3,451,408	86,259	3.63	14,254,315	312,817	14,567,132	$424,924,416,537	$289,352,850,836	$1,045,600,530,579	$712,003,082,395	$1,001,355,933,232
2032	3,562,431	3.31%	3,444,662	117,768	3.45	14,226,456	405,987	14,632,443	$436,988,086,958	$288,900,605,219	$1,075,285,292,628	$710,890,253,291	$999,790,858,510
2033	3,587,368	4.46%	3,427,218	160,150	3.21	14,154,409	513,781	14,668,190	$448,481,371,735	$287,863,126,633	$1,103,566,521,461	$708,337,356,547	$996,200,483,180
2034	3,612,479	6.00%	3,395,842	216,637	2.89	14,024,827	626,436	14,651,263	$458,625,370,439	$285,800,168,345	$1,128,527,596,923	$703,261,088,400	$989,061,256,745
2035	3,637,766	8.00%	3,346,745	291,021	2.48	13,822,057	721,151	14,543,208	$466,077,734,514	$281,984,694,423	$1,146,865,436,612	$693,872,450,321	$975,857,144,744
2036	3,663,231	10.58%	3,275,788	387,443	2.05	13,529,005	795,457	14,324,461	$469,993,183,993	$276,071,461,894	$1,156,500,081,960	$679,321,911,851	$955,393,373,745
2037	3,688,873	13.82%	3,178,940	509,934	1.99	13,129,022	1,012,750	14,141,772	$475,042,227,913	$270,909,944,724	$1,168,924,133,853	$666,621,099,939	$937,531,044,664
2038	3,714,696	17.81%	3,053,046	661,649	1.90	12,609,081	1,259,575	13,868,655	$476,955,501,952	$264,078,697,256	$1,173,632,077,836	$649,811,625,833	$913,890,323,090
2039	3,740,698	22.56%	2,896,866	843,833	1.81	11,964,056	1,523,687	13,487,742	$474,895,328,816	$255,279,640,138	$1,168,562,663,041	$628,160,013,372	$883,439,653,510
2040	3,766,883	28.00%	2,712,156	1,054,727	1.69	11,201,204	1,785,970	12,987,174	$468,153,654,817	$244,325,881,710	$1,151,973,600,056	$601,206,383,084	$845,532,264,794
2041	3,793,251	33.98%	2,504,377	1,288,874	1.57	10,343,079	2,023,342	12,366,421	$456,386,632,298	$231,247,340,679	$1,123,018,791,834	$569,024,355,154	$800,271,695,832
2042	3,819,804	40.24%	2,282,536	1,537,269	1.44	9,426,872	2,214,354	11,641,226	$439,848,119,395	$216,376,128,796	$1,082,322,900,534	$532,431,148,386	$748,807,277,182
2043	3,846,543	46.50%	2,057,927	1,788,616	1.31	8,499,237	2,345,393	10,844,630	$419,501,829,052	$200,356,409,871	$1,032,257,309,691	$493,011,840,019	$693,368,249,890
2044	3,873,469	52.44%	1,842,078	2,031,390	1.19	7,607,784	2,414,384	10,022,167	$396,913,535,004	$184,046,713,430	$976,674,878,267	$452,878,991,474	$636,925,704,904
2045	3,900,583	57.84%	1,644,639	2,255,944	1.08	6,792,360	2,430,069	9,222,429	$373,933,800,095	$168,340,904,383	$920,129,238,435	$414,232,113,033	$582,573,017,417
2046	3,912,285	62.52%	1,466,135	2,446,150	0.98	6,055,138	2,398,112	8,453,250	$350,903,937,146	$153,371,953,523	$863,460,249,832	$377,398,402,488	$530,770,356,011
2047	3,924,022	66.45%	1,316,352	2,607,670	0.90	5,436,532	2,344,881	7,781,413	$330,702,964,117	$140,332,599,826	$813,752,237,547	$345,312,801,818	$485,645,401,643
2048	3,935,794	69.65%	1,194,669	2,741,125	0.83	4,933,983	2,284,204	7,218,187	$314,067,434,879	$129,391,624,765	$772,817,620,658	$318,390,627,232	$447,782,251,997
2049	3,947,601	72.17%	1,098,441	2,849,160	0.78	4,536,561	2,225,471	6,762,033	$301,222,314,692	$120,485,053,713	$741,209,965,367	$296,474,458,012	$416,959,511,725
2050	3,959,444	74.14%	1,024,014	2,935,430	0.74	4,229,178	2,173,868	6,403,047	$292,019,377,038	$113,401,938,789	$718,564,534,509	$279,045,220,167	$392,447,158,957
2051	3,971,322	75.64%	967,503	3,003,819	0.71	3,995,788	2,131,451	6,127,239	$286,091,518,317	$107,864,011,374	$703,978,005,746	$265,418,185,290	$373,282,196,664
2052	3,983,236	76.77%	925,272	3,057,964	0.69	3,821,373	2,098,320	5,919,693	$282,979,155,565	$103,583,076,628	$696,319,495,154	$254,884,199,793	$358,467,276,421
2053	3,995,186	77.62%	894,167	3,101,019	0.67	3,692,910	2,073,558	5,766,468	$282,215,122,199	$100,294,569,040	$694,439,457,996	$246,792,254,155	$347,086,823,195
2054	4,007,171	78.25%	871,588	3,135,583	0.66	3,599,659	2,055,852	5,655,511	$283,372,265,736	$97,772,620,041	$697,286,811,193	$240,586,559,426	$338,359,179,467
2055	4,019,193	78.72%	855,463	3,163,730	0.65	3,533,061	2,043,845	5,576,906	$286,084,252,600	$95,833,343,151	$703,960,127,185	$235,814,630,899	$331,647,974,049
2056	4,031,250	79.06%	844,179	3,187,072	0.64	3,486,458	2,036,312	5,522,770	$290,049,889,788	$94,331,809,653	$713,718,268,130	$232,119,846,225	$326,451,655,878
2057	4,043,344	79.31%	836,503	3,206,842	0.63	3,454,756	2,032,224	5,486,980	$295,028,700,004	$93,156,358,197	$725,969,497,764	$229,227,443,205	$322,383,801,402
2058	4,055,474	79.50%	831,503	3,223,971	0.63	3,434,108	2,030,753	5,464,860	$300,832,734,912	$92,222,332,816	$740,251,336,468	$226,929,111,086	$319,151,443,902
2059	4,067,641	79.63%	828,483	3,239,158	0.63	3,421,633	2,031,250	5,452,882	$307,317,480,460	$91,466,287,305	$756,208,182,256	$225,068,729,437	$316,535,016,742
2060	4,079,844	79.73%	826,922	3,252,922	0.63	3,415,186	2,033,219	5,448,405	$314,373,298,296	$90,841,064,332	$773,570,250,864	$223,530,259,423	$314,371,323,754
					TOTALS	**389,871,392**	**53,253,214**	**443,124,605**	**$15,124,954,931,844**	**$8,542,747,620,205**	**$37,217,585,731,166**	**$21,020,918,301,403**	**$29,563,665,921,607**

Appendix C

Full Model: VMT Bear Case with AV Mandate

Note: Since the non-AV crash rate, average economic cost per accident, and average societal cost per accident columns are the same for all models to conserve space they are not shown. Refer to appendix A to see figures used.

Year	Vehicle Miles Traveled (Millions)	AV Adoption	Non-AV Miles Driven	AV Miles Driven	AV Crash Rate (per million miles)	Non-AV Accidents	AV Accidents	Total Accidents	Economic Cost	PV Economic Cost	Societal Cost	PV Societal Cost	Total PV Costs
2020	3,259,803	0.10%	3,256,645	3,158	4.11	13,449,944	12,981	13,462,924	$303,187,058,853	$285,782,881,377	$746,044,560,549	$703,218,550,805	$989,001,432,182
2021	3,277,080	0.14%	3,272,590	4,490	4.10	13,515,798	18,417	13,534,214	$312,046,581,966	$285,566,826,816	$767,844,960,120	$702,686,910,930	$988,253,737,746
2022	3,294,449	0.19%	3,288,067	6,382	4.09	13,579,715	26,103	13,605,818	$321,163,487,172	$285,349,598,616	$790,278,693,154	$702,152,383,111	$987,501,981,727
2023	3,311,909	0.27%	3,302,840	9,069	4.07	13,640,729	36,943	13,677,673	$330,543,664,960	$285,129,869,017	$813,360,254,228	$701,611,700,166	$986,741,569,184
2024	3,329,462	0.39%	3,316,579	12,884	4.05	13,697,470	52,180	13,749,650	$340,191,464,538	$284,904,995,809	$837,100,345,325	$701,058,360,474	$985,963,356,283
2025	3,347,109	0.55%	3,328,815	18,294	4.02	13,748,005	73,489	13,821,494	$350,107,863,201	$284,669,731,624	$861,501,371,248	$700,479,451,973	$985,149,183,596
2026	3,364,848	0.77%	3,338,889	25,959	3.97	13,789,614	103,074	13,892,688	$360,286,747,087	$284,413,685,151	$886,548,287,776	$699,849,405,036	$984,263,090,187
2027	3,382,682	1.09%	3,345,881	36,801	3.91	13,818,489	143,720	13,962,209	$370,707,410,146	$284,116,361,940	$912,190,144,068	$699,117,789,493	$983,234,151,433
2028	3,400,610	1.53%	3,348,507	52,103	3.81	13,829,334	198,701	14,028,035	$381,319,571,195	$283,737,572,557	$938,303,214,513	$698,185,712,247	$981,923,284,804
2029	3,418,633	2.15%	3,345,000	73,633	3.69	13,814,850	271,356	14,086,206	$392,013,842,978	$283,199,140,889	$964,618,332,722	$696,860,807,355	$980,059,948,244
2030	3,436,752	3.02%	3,332,958	103,795	3.51	13,765,115	363,939	14,129,054	$402,564,616,810	$282,350,722,708	$990,580,349,229	$694,773,126,664	$977,123,849,372
2031	3,454,967	4.22%	3,309,176	145,791	3.26	13,666,898	475,077	14,141,975	$412,522,547,932	$280,907,781,792	$1,015,083,573,001	$691,222,519,240	$972,130,301,032
2032	3,473,278	5.87%	3,269,500	203,778	2.92	13,503,037	594,718	14,097,754	$421,019,970,435	$278,343,799,060	$1,035,992,960,959	$684,913,393,193	$963,257,192,253
2033	3,491,687	8.10%	3,208,757	282,929	2.46	13,252,167	695,085	13,947,252	$426,438,621,482	$273,714,724,030	$1,049,326,495,558	$673,522,747,894	$947,237,471,923
2034	3,510,193	11.09%	3,120,892	389,301	2.04	12,889,282	795,139	13,684,422	$428,360,538,606	$266,940,125,726	$1,054,055,707,356	$656,852,668,921	$923,792,794,646
2035	3,528,797	15.00%	2,999,477	529,319	1.96	12,387,841	1,038,393	13,426,233	$430,281,145,239	$260,327,169,206	$1,058,781,694,464	$640,580,337,710	$900,907,506,916
2036	3,547,499	19.98%	2,838,786	708,713	1.86	11,724,186	1,317,468	13,041,654	$427,903,604,789	$251,348,270,033	$1,052,931,342,121	$618,486,192,552	$869,834,462,585
2037	3,566,301	26.10%	2,635,485	930,816	1.73	10,884,552	1,612,665	12,497,218	$419,799,307,637	$239,405,679,211	$1,032,989,307,557	$589,099,367,946	$828,505,047,157
2038	3,585,202	33.32%	2,390,687	1,194,515	1.58	9,873,538	1,891,497	11,765,035	$404,610,100,873	$224,022,802,752	$995,613,619,001	$551,247,121,379	$775,269,924,131
2039	3,604,204	41.41%	2,111,597	1,492,607	1.42	8,720,895	2,114,013	10,834,908	$381,490,635,003	$205,070,014,612	$938,724,146,806	$504,610,485,394	$709,680,500,006
2040	3,623,306	50.00%	1,811,653	1,811,653	1.24	7,482,127	2,244,638	9,726,766	$350,624,460,611	$182,988,276,619	$862,772,549,144	$450,274,523,366	$633,262,799,985
2041	3,642,510	58.59%	1,508,471	2,134,039	1.06	6,229,984	2,265,661	8,495,645	$313,534,417,734	$158,865,302,315	$771,506,039,144	$390,915,743,898	$549,781,046,213
2042	3,661,815	66.68%	1,220,041	2,441,774	0.89	5,038,769	2,184,204	7,222,973	$272,910,361,345	$134,253,813,742	$671,543,473,423	$330,354,889,995	$464,608,703,738
2043	3,681,223	73.90%	960,811	2,720,412	0.75	3,968,150	2,027,990	5,996,140	$231,948,134,580	$110,779,720,855	$570,748,780,596	$272,592,796,262	$383,372,517,117
2044	3,700,733	80.02%	739,326	2,961,407	0.62	3,053,416	1,833,236	4,886,652	$193,528,836,049	$89,738,300,883	$476,211,405,558	$220,816,717,903	$310,555,018,786
2045	3,720,347	85.00%	558,052	3,162,295	0.52	2,304,755	1,632,535	3,937,290	$159,641,855,450	$71,869,016,166	$392,826,588,130	$176,846,230,790	$248,715,246,956
2046	3,727,788	88.91%	413,434	3,314,354	0.44	1,707,481	1,443,470	3,150,950	$130,799,489,288	$57,169,416,094	$321,854,923,080	$140,675,304,772	$197,844,720,866
2047	3,735,243	91.90%	302,665	3,432,579	0.41	1,250,005	1,417,655	2,667,660	$113,373,130,435	$48,109,475,483	$278,974,332,195	$118,381,743,042	$166,491,218,525
2048	3,742,714	94.13%	219,586	3,523,128	0.41	906,889	1,455,052	2,361,941	$102,769,398,905	$42,339,631,632	$252,882,004,047	$104,184,037,387	$146,523,669,020
2049	3,750,199	95.78%	158,249	3,591,950	0.41	653,568	1,483,476	2,137,043	$95,196,984,533	$38,077,570,071	$234,248,759,693	$93,696,492,647	$131,774,062,719
2050	3,757,700	96.98%	113,488	3,644,212	0.41	468,704	1,505,060	1,973,763	$90,016,074,997	$34,956,575,589	$221,500,229,487	$86,016,742,180	$120,973,317,769
2051	3,765,215	97.85%	81,098	3,684,117	0.41	334,937	1,521,540	1,856,477	$86,682,143,609	$32,681,443,264	$213,296,510,678	$80,418,382,863	$113,099,826,126
2052	3,772,745	98.47%	57,805	3,714,940	0.41	238,735	1,534,270	1,773,005	$84,754,983,635	$31,024,129,487	$208,554,397,933	$76,340,273,682	$107,364,403,170
2053	3,780,291	98.91%	41,127	3,739,164	0.41	169,853	1,544,275	1,714,128	$83,890,648,928	$29,813,343,860	$206,427,551,856	$73,360,924,780	$103,174,268,640
2054	3,787,852	99.23%	29,222	3,758,629	0.41	120,687	1,552,314	1,673,001	$83,826,592,647	$28,922,892,545	$206,269,930,221	$71,169,814,240	$100,092,706,786
2055	3,795,427	99.45%	20,744	3,774,683	0.41	85,674	1,558,944	1,644,618	$84,365,642,844	$28,261,050,817	$207,596,357,109	$69,541,237,404	$97,802,288,222
2056	3,803,018	99.61%	14,716	3,788,302	0.41	60,778	1,564,569	1,625,347	$85,361,445,307	$27,761,774,419	$210,046,702,497	$68,312,680,873	$96,074,455,291
2057	3,810,624	99.73%	10,435	3,800,189	0.41	43,096	1,569,478	1,612,575	$86,706,306,893	$27,377,823,862	$213,355,968,646	$67,367,903,660	$94,745,727,521
2058	3,818,245	99.81%	7,397	3,810,849	0.41	30,549	1,573,880	1,604,429	$88,321,523,853	$27,075,567,325	$217,330,491,279	$66,624,148,810	$93,699,716,135
2059	3,825,882	99.86%	5,242	3,820,640	0.41	21,649	1,577,924	1,599,573	$90,149,916,248	$26,831,139,341	$221,829,569,195	$66,022,691,187	$92,853,830,528
2060	3,833,534	99.90%	3,714	3,829,819	0.41	15,340	1,581,715	1,597,055	$92,150,177,688	$26,627,643,839	$226,751,560,829	$65,521,955,065	$92,149,598,904
					TOTALS	**291,736,604**	**46,906,844**	**338,643,448**	**$10,537,111,306,485**	**$6,664,825,661,135**	**$25,928,397,484,498**	**$16,399,964,267,288**	**$23,064,789,928,423**

Appendix D

Full Model: VMT Bear Case without AV Mandate

Note: Since the non-AV crash rate, average economic cost per accident, and average societal cost per accident columns are the same for all models to conserve space they are not shown. Refer to appendix A to see figures used.

Year	Vehicle Miles Traveled (Millions)	AV Adoption	Non-AV Miles Driven	AV Miles Driven	AV Crash Rate (per million miles)	Non-AV Accidents	AV Accidents	Total Accidents	Economic Cost	PV Economic Cost	Societal Cost	PV Societal Cost	Total PV Costs
2020	3,259,803	0.08%	3,257,260	2,543	4.11	13,452,483	10,463	13,462,947	$303,187,559,017	$285,783,352,830	$746,045,791,289	$703,219,710,896	$989,003,063,726
2021	3,277,080	0.11%	3,273,576	3,505	4.11	13,519,867	14,397	13,534,264	$312,047,726,478	$285,567,874,206	$767,847,776,389	$702,689,488,216	$988,257,362,422
2022	3,294,449	0.15%	3,289,620	4,828	4.10	13,586,132	19,795	13,605,927	$321,166,064,232	$285,351,888,300	$790,285,034,457	$702,158,017,277	$987,509,905,577
2023	3,311,909	0.20%	3,305,258	6,651	4.09	13,650,717	27,192	13,677,910	$330,549,393,469	$285,134,810,480	$813,374,350,223	$701,623,859,495	$986,758,669,974
2024	3,329,462	0.28%	3,320,303	9,159	4.07	13,712,853	37,307	13,750,160	$340,204,063,387	$284,915,547,146	$837,131,346,986	$701,084,323,877	$985,999,871,024
2025	3,347,109	0.38%	3,334,500	12,609	4.05	13,771,484	51,093	13,822,578	$350,135,319,006	$284,692,055,706	$861,568,931,038	$700,534,384,264	$985,226,439,970
2026	3,364,848	0.52%	3,347,499	17,350	4.02	13,825,170	69,807	13,894,976	$360,346,087,528	$284,460,529,043	$886,694,305,265	$699,964,672,590	$984,425,201,634
2027	3,382,682	0.71%	3,358,824	23,858	3.98	13,871,945	95,057	13,967,002	$370,834,664,379	$284,213,891,713	$912,503,275,271	$699,357,778,486	$983,571,670,199
2028	3,400,610	0.96%	3,367,832	32,778	3.93	13,909,147	128,849	14,037,996	$381,590,334,938	$283,939,046,211	$938,969,475,858	$698,681,473,260	$982,620,519,470
2029	3,418,633	1.32%	3,373,653	44,980	3.86	13,933,188	173,547	14,106,735	$392,585,168,877	$283,611,878,874	$966,024,179,595	$697,876,421,048	$981,488,299,922
2030	3,436,752	1.79%	3,375,128	61,625	3.76	13,939,277	231,691	14,170,968	$403,758,834,624	$283,188,323,055	$993,518,930,142	$696,834,188,192	$980,022,511,248
2031	3,454,967	2.44%	3,370,725	84,242	3.63	13,921,092	305,504	14,226,597	$414,990,977,639	$282,588,662,308	$1,021,157,574,189	$695,358,618,488	$977,947,280,797
2032	3,473,278	3.31%	3,358,457	114,821	3.45	13,870,429	395,827	14,266,256	$426,052,165,991	$281,670,673,144	$1,048,375,554,518	$693,099,746,277	$974,770,419,421
2033	3,491,687	4.46%	3,335,808	155,879	3.21	13,776,888	500,078	14,276,966	$436,519,652,479	$280,185,354,217	$1,074,132,628,011	$689,444,860,378	$969,630,214,595
2034	3,510,193	6.00%	3,299,689	210,503	2.89	13,627,717	608,699	14,236,416	$445,639,501,320	$277,707,804,033	$1,096,573,604,370	$683,348,416,665	$961,056,220,698
2035	3,528,797	8.00%	3,246,493	282,304	2.48	13,408,016	699,549	14,107,564	$452,116,307,833	$273,537,801,673	$1,112,510,914,780	$673,087,399,624	$946,625,201,297
2036	3,547,499	10.58%	3,172,297	375,202	2.05	13,101,586	770,326	13,871,912	$455,144,802,521	$267,349,602,685	$1,119,963,053,394	$657,860,258,293	$925,209,860,979
2037	3,566,301	13.82%	3,073,311	492,990	1.99	12,692,776	979,099	13,671,875	$459,257,711,200	$261,908,255,403	$1,130,083,581,492	$644,470,875,654	$906,379,131,057
2038	3,585,202	17.81%	2,946,618	638,584	1.90	12,169,532	1,215,666	13,385,198	$460,328,978,155	$254,872,994,154	$1,132,719,620,403	$627,159,390,109	$882,032,384,262
2039	3,604,204	22.56%	2,791,162	813,042	1.81	11,527,499	1,468,089	12,995,588	$457,566,859,310	$245,964,733,902	$1,125,922,945,942	$605,239,064,321	$851,203,798,223
2040	3,623,306	28.00%	2,608,781	1,014,526	1.69	10,774,263	1,717,896	12,492,160	$450,309,691,874	$235,013,251,264	$1,108,065,421,578	$578,291,034,009	$813,304,285,273
2041	3,642,510	33.98%	2,404,855	1,237,655	1.57	9,932,051	1,942,936	11,874,986	$438,250,079,297	$222,057,698,929	$1,078,390,644,563	$546,411,641,184	$768,469,340,113
2042	3,661,815	40.24%	2,188,129	1,473,686	1.44	9,036,972	2,122,767	11,159,739	$421,655,762,068	$207,426,694,483	$1,037,557,436,998	$510,409,506,649	$717,836,201,132
2043	3,681,223	46.50%	1,969,479	1,711,744	1.31	8,133,949	2,244,591	10,378,539	$401,472,100,976	$191,745,311,329	$987,892,023,749	$471,822,732,372	$663,568,043,701
2044	3,700,733	52.44%	1,759,932	1,940,801	1.19	7,268,518	2,306,715	9,575,233	$379,213,362,990	$175,839,236,993	$933,120,522,413	$432,683,066,307	$608,522,303,300
2045	3,720,347	57.84%	1,568,645	2,151,702	1.08	6,478,503	2,317,782	8,796,285	$356,655,281,072	$160,562,304,220	$877,612,433,200	$395,091,512,631	$555,653,816,850
2046	3,727,788	62.52%	1,396,995	2,330,793	0.98	5,769,587	2,285,021	8,054,609	$334,355,880,347	$146,139,182,586	$822,740,874,113	$359,600,909,958	$505,740,092,543
2047	3,735,243	66.45%	1,253,024	2,482,219	0.90	5,174,989	2,232,072	7,407,062	$314,793,387,170	$133,581,428,722	$774,603,952,699	$328,700,369,552	$462,281,798,274
2048	3,742,714	69.65%	1,136,062	2,606,652	0.83	4,691,935	2,172,147	6,864,082	$298,660,101,972	$123,044,007,608	$734,905,194,740	$302,771,209,732	$425,815,217,340
2049	3,750,199	72.17%	1,043,513	2,706,686	0.78	4,309,708	2,114,185	6,423,894	$286,159,541,665	$114,460,138,131	$704,145,389,041	$281,649,103,941	$396,109,242,072
2050	3,757,700	74.14%	971,838	2,785,862	0.74	4,013,690	2,063,104	6,076,794	$277,140,214,486	$107,623,808,934	$681,951,763,736	$264,827,125,354	$372,450,934,288
2051	3,765,215	75.64%	917,291	2,847,924	0.71	3,788,412	2,020,831	5,809,243	$271,243,693,616	$102,265,991,755	$667,442,347,213	$251,643,283,082	$353,909,274,836
2052	3,772,745	76.77%	876,377	2,896,369	0.69	3,619,436	1,987,436	5,606,872	$268,025,368,567	$98,109,319,166	$659,523,097,934	$241,415,066,261	$339,524,385,427
2053	3,780,291	77.62%	846,071	2,934,220	0.67	3,494,274	1,962,025	5,456,299	$267,035,207,676	$94,899,879,438	$657,086,634,617	$233,517,680,865	$328,417,560,303
2054	3,787,852	78.25%	823,885	2,963,967	0.66	3,402,643	1,943,331	5,345,974	$267,862,782,127	$92,421,345,300	$659,123,025,683	$227,418,815,962	$319,840,161,262
2055	3,795,427	78.72%	807,835	2,987,592	0.65	3,336,361	1,930,055	5,266,416	$270,156,719,494	$90,497,891,332	$664,767,658,080	$222,685,822,492	$313,183,713,824
2056	3,803,018	79.06%	796,385	3,006,633	0.64	3,289,069	1,921,025	5,210,094	$273,628,490,384	$88,991,141,108	$673,310,554,989	$218,978,201,154	$307,969,342,262
2057	3,810,624	79.31%	788,357	3,022,268	0.63	3,255,913	1,915,257	5,171,170	$278,047,928,457	$87,794,619,367	$684,185,352,045	$216,033,951,028	$303,828,570,395
2058	3,818,245	79.50%	782,864	3,035,382	0.63	3,233,227	1,911,962	5,145,188	$283,235,234,475	$86,827,698,676	$696,949,621,911	$213,654,674,271	$300,482,372,948
2059	3,825,882	79.63%	779,242	3,046,640	0.63	3,218,269	1,910,523	5,128,792	$289,052,173,367	$86,030,020,472	$711,263,213,117	$211,691,848,128	$297,721,868,600
2060	3,833,534	79.73%	776,998	3,056,535	0.63	3,209,003	1,910,468	5,119,472	$295,393,826,916	$85,356,771,009	$726,867,956,120	$210,035,200,573	$295,391,971,582
					TOTALS	**378,698,570**	**50,734,167**	**429,432,736**	**$14,596,369,001,377**	**$8,287,332,819,905**	**$35,916,907,992,153**	**$20,392,425,702,913**	**$28,679,758,522,819**

Appendix E

Full Model: VMT Bull Case with AV Mandate

Note: Since the non-AV crash rate, average economic cost per accident, and average societal cost per accident columns are the same for all models to conserve space they are not shown. Refer to appendix A to see figures used.

Year	Vehicle Miles Traveled (Millions)	AV Adoption	Non-AV Miles Driven	AV Miles Driven	AV Crash Rate (per million miles)	Non-AV Accidents	AV Accidents	Total Accidents	Economic Cost	PV Economic Cost	Societal Cost	PV Societal Cost	Total PV Costs
2020	3,294,949	0.10%	3,291,757	3,192	4.11	13,594,955	13,121	13,608,076	$306,455,894,025	$288,864,072,038	$754,088,098,782	$710,800,357,038	$999,664,429,076
2021	3,324,274	0.14%	3,319,719	4,555	4.10	13,710,441	18,682	13,729,123	$316,540,429,845	$289,679,334,220	$778,902,855,460	$712,806,451,621	$1,002,485,785,841
2022	3,353,860	0.19%	3,347,363	6,497	4.09	13,824,609	26,573	13,851,183	$326,955,285,293	$290,495,536,231	$804,530,421,115	$714,814,858,815	$1,005,310,395,045
2023	3,383,710	0.27%	3,374,444	9,266	4.07	13,936,452	37,744	13,974,196	$337,709,653,318	$291,311,313,523	$830,993,416,591	$716,822,220,916	$1,008,133,534,440
2024	3,413,825	0.39%	3,400,614	13,210	4.05	14,044,537	53,502	14,098,040	$348,811,254,595	$292,123,934,277	$858,310,839,957	$718,821,815,805	$1,010,945,750,082
2025	3,444,208	0.55%	3,425,383	18,825	4.02	14,146,832	75,621	14,222,453	$360,264,426,401	$292,927,946,946	$886,493,363,841	$720,800,229,001	$1,013,728,175,947
2026	3,474,861	0.77%	3,448,054	26,808	3.97	14,240,461	106,444	14,346,905	$372,066,220,344	$293,712,510,116	$915,533,733,207	$722,730,783,320	$1,016,443,293,436
2027	3,505,787	1.09%	3,467,647	38,140	3.91	14,321,383	148,951	14,470,333	$384,198,497,495	$294,456,157,022	$945,387,314,061	$724,560,656,042	$1,019,016,813,064
2028	3,536,989	1.53%	3,482,796	54,193	3.81	14,383,948	206,670	14,590,618	$396,612,073,101	$295,116,630,169	$975,933,078,755	$726,185,865,248	$1,021,302,495,417
2029	3,568,468	2.15%	3,491,607	76,861	3.69	14,420,338	283,249	14,703,587	$409,195,337,948	$295,611,418,418	$1,006,896,393,377	$727,403,377,906	$1,023,014,796,324
2030	3,600,227	3.02%	3,491,496	108,732	3.51	14,419,877	381,251	14,801,128	$421,713,314,931	$295,781,234,302	$1,037,699,055,843	$727,821,239,463	$1,023,602,473,766
2031	3,632,269	4.22%	3,478,997	153,273	3.26	14,368,257	499,457	14,867,714	$433,692,432,493	$295,323,443,051	$1,067,175,760,853	$726,694,764,361	$1,022,018,207,412
2032	3,664,597	5.87%	3,449,594	215,003	2.92	14,246,823	627,477	14,874,300	$444,210,979,363	$293,675,787,997	$1,093,058,477,308	$722,640,422,149	$1,016,316,210,146
2033	3,697,212	8.10%	3,397,629	299,583	2.46	14,032,206	735,998	14,768,204	$451,539,307,337	$289,825,899,133	$1,111,091,104,570	$713,167,100,114	$1,002,992,999,248
2034	3,730,117	11.09%	3,316,425	413,692	2.04	13,696,835	844,957	14,541,792	$455,198,609,884	$283,664,724,459	$1,120,095,455,782	$698,006,456,814	$981,671,181,272
2035	3,763,315	15.00%	3,198,818	564,497	1.96	13,211,116	1,107,402	14,318,519	$458,876,932,514	$277,628,090,790	$1,129,146,609,221	$683,152,268,348	$960,780,359,138
2036	3,796,808	19.98%	3,038,289	758,520	1.86	12,548,132	1,410,056	13,958,188	$457,975,552,476	$269,012,369,944	$1,126,928,606,654	$661,951,786,717	$930,964,156,662
2037	3,830,600	26.10%	2,830,801	999,799	1.73	11,691,207	1,732,180	13,423,387	$450,910,665,151	$257,148,051,676	$1,109,544,220,989	$632,757,565,360	$889,905,617,036
2038	3,864,692	33.32%	2,577,057	1,287,635	1.58	10,643,244	2,038,951	12,682,195	$436,152,081,613	$241,486,832,727	$1,073,228,155,879	$594,220,408,620	$835,707,241,347
2039	3,899,088	41.41%	2,284,361	1,614,727	1.42	9,434,410	2,286,975	11,721,385	$412,702,927,663	$221,848,159,931	$1,015,527,428,745	$545,896,033,988	$767,744,193,919
2040	3,933,790	50.00%	1,966,895	1,966,895	1.24	8,123,276	2,436,983	10,560,259	$380,669,707,609	$198,668,665,714	$936,704,111,981	$488,858,851,589	$687,527,517,303
2041	3,968,801	58.59%	1,643,597	2,325,203	1.06	6,788,057	2,468,616	9,256,672	$341,620,378,291	$173,096,226,776	$840,616,436,470	$425,933,411,954	$599,029,638,729
2042	4,004,123	66.68%	1,334,091	2,670,032	0.89	5,509,795	2,388,384	7,898,180	$298,422,120,105	$146,803,908,550	$734,319,598,910	$361,236,583,959	$508,040,492,509
2043	4,039,760	73.90%	1,054,390	2,985,369	0.75	4,354,632	2,225,508	6,580,141	$254,538,986,511	$121,569,237,552	$626,337,506,134	$299,142,281,167	$420,711,518,719
2044	4,075,713	80.02%	814,239	3,261,475	0.62	3,362,807	2,018,990	5,381,797	$213,138,326,039	$98,831,118,000	$524,463,970,816	$243,191,177,999	$342,022,295,998
2045	4,111,987	85.00%	616,798	3,495,189	0.52	2,547,376	1,804,391	4,351,768	$176,447,322,354	$79,434,653,443	$434,179,366,243	$195,462,798,922	$274,897,452,365
2046	4,128,435	88.91%	457,868	3,670,568	0.44	1,890,994	1,598,608	3,489,602	$144,857,286,278	$63,313,752,359	$356,446,580,841	$155,794,514,233	$219,108,266,592
2047	4,144,949	91.90%	335,863	3,809,086	0.41	1,387,114	1,573,153	2,960,266	$125,808,628,067	$53,386,433,666	$309,574,039,850	$131,366,617,673	$184,753,051,339
2048	4,161,529	94.13%	244,158	3,917,371	0.41	1,008,371	1,617,874	2,626,246	$114,269,439,099	$47,077,495,926	$281,179,855,761	$115,842,377,616	$162,919,873,542
2049	4,178,175	95.78%	176,308	4,001,867	0.41	728,153	1,652,771	2,380,924	$106,060,937,683	$42,423,011,677	$260,981,408,456	$104,389,208,508	$146,812,220,185
2050	4,194,888	96.98%	126,691	4,068,196	0.41	523,235	1,680,165	2,203,400	$100,488,955,966	$39,023,583,123	$247,270,577,041	$96,024,322,517	$135,047,905,641
2051	4,211,667	97.85%	90,715	4,120,953	0.41	374,651	1,701,953	2,076,604	$96,960,287,769	$36,556,573,380	$238,587,674,398	$89,953,815,395	$126,510,388,775
2052	4,228,514	98.47%	64,788	4,163,726	0.41	267,575	1,719,619	1,987,194	$94,993,849,824	$34,772,014,235	$233,748,911,366	$85,562,596,826	$120,334,611,061
2053	4,245,428	98.91%	46,187	4,199,241	0.41	190,752	1,734,287	1,925,038	$94,212,773,599	$33,481,655,599	$231,826,937,283	$82,387,444,675	$115,869,100,274
2054	4,262,410	99.23%	32,883	4,229,526	0.41	135,808	1,746,794	1,882,602	$94,328,741,525	$32,546,474,441	$232,112,296,562	$80,086,268,568	$112,632,743,009
2055	4,279,459	99.45%	23,390	4,256,069	0.41	96,600	1,757,757	1,854,356	$95,124,817,872	$31,865,190,867	$234,071,181,056	$78,409,851,685	$110,275,042,552
2056	4,296,577	99.61%	16,626	4,279,951	0.41	68,666	1,767,620	1,836,286	$96,439,726,322	$31,364,721,128	$237,306,742,299	$77,178,358,731	$108,543,079,859
2057	4,313,763	99.73%	11,813	4,301,951	0.41	48,787	1,776,706	1,825,492	$98,154,652,385	$30,992,679,547	$241,526,616,543	$76,262,885,626	$107,255,565,173
2058	4,331,018	99.81%	8,390	4,322,628	0.41	34,651	1,785,245	1,819,897	$100,182,703,113	$30,711,692,966	$246,516,988,558	$75,571,469,210	$106,283,162,176
2059	4,348,342	99.86%	5,958	4,342,385	0.41	24,606	1,793,405	1,818,010	$102,460,745,367	$30,495,186,799	$252,122,508,264	$75,038,718,079	$105,533,904,878
2060	4,365,736	99.90%	4,230	4,361,506	0.41	17,469	1,801,302	1,818,771	$104,943,211,769	$30,324,309,040	$258,231,049,184	$74,618,243,593	$104,942,552,633
					TOTALS	**306,399,438**	**51,685,392**	**358,084,830**	**$11,215,905,473,340**	**$7,036,432,031,760**	**$27,598,688,749,005**	**$17,314,366,460,173**	**$24,350,798,491,933**

Appendix F

Full Model: VMT Bull Case without AV Mandate

Note: Since the non-AV crash rate, average economic cost per accident, and average societal cost per accident columns are the same for all models to conserve space they are not shown. Refer to appendix A to see figures used.

Year	Vehicle Miles Traveled (Millions)	AV Adoption	Non-AV Miles Driven	AV Miles Driven	AV Crash Rate (per million miles)	Non-AV Accidents	AV Accidents	Total Accidents	Economic Cost	PV Economic Cost	Societal Cost	PV Societal Cost	Total PV Costs
2020	3,294,949	0.08%	3,292,378	2,571	4.11	13,597,522	10,576	13,608,098	$306,456,399,582	$288,864,548,574	$754,089,342,792	$710,801,529,637	$999,666,078,210
2021	3,324,274	0.11%	3,320,719	3,555	4.11	13,714,570	14,604	13,729,174	$316,541,590,838	$289,680,396,694	$778,905,712,288	$712,809,066,023	$1,002,489,462,717
2022	3,353,860	0.15%	3,348,945	4,915	4.10	13,831,142	20,152	13,851,294	$326,957,908,827	$290,497,867,206	$804,536,876,776	$714,820,594,586	$1,005,318,461,793
2023	3,383,710	0.20%	3,376,914	6,795	4.09	13,946,657	27,782	13,974,439	$337,715,506,017	$291,316,362,113	$831,007,818,177	$716,834,643,852	$1,008,151,005,965
2024	3,413,825	0.28%	3,404,433	9,391	4.07	14,060,310	38,252	14,098,562	$348,824,172,674	$292,134,752,965	$858,342,627,141	$718,848,437,071	$1,010,983,190,036
2025	3,444,208	0.38%	3,431,233	12,975	4.05	14,170,992	52,576	14,223,568	$360,292,678,694	$292,950,918,645	$886,562,883,527	$720,856,754,868	$1,013,807,673,513
2026	3,474,861	0.52%	3,456,944	17,917	4.02	14,277,180	72,089	14,349,268	$372,127,500,904	$293,760,885,556	$915,684,524,697	$722,849,819,514	$1,016,610,705,070
2027	3,505,787	0.71%	3,481,061	24,726	3.98	14,376,784	98,517	14,475,300	$384,330,382,868	$294,557,236,178	$945,711,840,991	$724,809,378,911	$1,019,366,615,089
2028	3,536,989	0.96%	3,502,896	34,093	3.93	14,466,961	134,017	14,600,978	$396,893,695,597	$295,326,183,755	$976,626,059,953	$726,701,508,341	$1,022,027,692,096
2029	3,568,468	1.32%	3,521,516	46,952	3.86	14,543,863	181,153	14,725,016	$409,791,704,372	$296,042,246,212	$1,008,363,856,827	$728,463,504,725	$1,024,505,750,937
2030	3,600,227	1.79%	3,535,672	64,556	3.76	14,602,324	242,712	14,845,036	$422,964,337,828	$296,658,676,592	$1,040,777,415,555	$729,980,339,029	$1,026,639,015,621
2031	3,632,269	2.44%	3,543,704	88,566	3.63	14,635,497	321,182	14,956,679	$436,287,537,389	$297,090,583,207	$1,073,561,468,407	$731,043,120,477	$1,028,133,703,684
2032	3,664,597	3.31%	3,543,451	121,146	3.45	14,634,453	417,631	15,052,083	$449,520,362,939	$297,185,916,017	$1,106,123,140,265	$731,277,703,457	$1,028,463,619,474
2033	3,697,212	4.46%	3,532,158	165,054	3.21	14,587,812	529,513	15,117,325	$462,213,719,841	$296,677,398,331	$1,137,357,355,565	$730,026,407,129	$1,026,703,805,460
2034	3,730,117	6.00%	3,506,425	223,692	2.89	14,481,534	646,836	15,128,370	$473,560,151,386	$295,107,030,076	$1,165,277,226,444	$726,162,242,546	$1,021,269,272,622
2035	3,763,315	8.00%	3,462,250	301,065	2.48	14,299,091	746,040	15,045,130	$482,163,224,612	$291,716,680,472	$1,186,446,586,405	$717,819,696,891	$1,009,536,377,363
2036	3,796,808	10.58%	3,395,238	401,571	2.05	14,022,331	824,462	14,846,794	$487,131,190,432	$286,138,234,462	$1,198,671,131,513	$704,092,958,956	$990,231,193,418
2037	3,830,600	13.82%	3,301,075	529,525	1.99	13,633,439	1,051,660	14,685,098	$493,293,333,899	$281,318,295,442	$1,213,834,158,694	$692,232,659,570	$973,550,955,012
2038	3,864,692	17.81%	3,176,326	688,366	1.90	13,118,226	1,310,435	14,428,661	$496,214,606,645	$274,741,996,572	$1,221,022,459,047	$676,050,530,891	$950,792,527,463
2039	3,899,088	22.56%	3,019,526	879,562	1.81	12,470,641	1,588,203	14,058,844	$495,003,455,163	$266,088,748,895	$1,218,042,209,895	$654,757,707,956	$920,846,456,851
2040	3,933,790	28.00%	2,832,329	1,101,461	1.69	11,697,517	1,865,104	13,562,622	$488,897,033,710	$255,151,695,597	$1,203,016,296,433	$627,845,183,548	$882,996,879,145
2041	3,968,801	33.98%	2,620,278	1,348,522	1.57	10,821,749	2,116,981	12,938,730	$477,507,888,791	$241,949,307,061	$1,174,991,321,857	$595,358,407,262	$837,307,714,322
2042	4,004,123	40.24%	2,392,676	1,611,447	1.44	9,881,751	2,321,204	12,202,955	$461,072,294,399	$226,817,016,506	$1,134,548,679,477	$558,122,770,954	$784,939,787,461
2043	4,039,760	46.50%	2,161,299	1,878,461	1.31	8,926,164	2,463,205	11,389,369	$440,573,932,098	$210,420,563,641	$1,084,108,889,095	$517,776,443,118	$728,197,006,759
2044	4,075,713	52.44%	1,938,258	2,137,455	1.19	8,005,007	2,540,446	10,545,453	$417,637,511,027	$193,656,311,844	$1,027,669,830,506	$476,525,081,953	$670,181,393,797
2045	4,111,987	57.84%	1,733,776	2,378,212	1.08	7,160,493	2,561,775	9,722,268	$394,200,312,764	$177,464,666,586	$969,998,522,420	$436,682,718,902	$614,147,385,488
2046	4,128,435	62.52%	1,547,138	2,581,297	0.98	6,389,679	2,530,606	8,920,285	$370,291,090,139	$161,845,627,406	$911,165,716,186	$398,249,352,831	$560,094,980,237
2047	4,144,949	66.45%	1,390,464	2,754,485	0.90	5,742,616	2,476,901	8,219,516	$349,321,960,258	$148,233,503,108	$859,567,520,186	$364,754,350,343	$512,987,853,451
2048	4,161,529	69.65%	1,263,189	2,898,340	0.83	5,216,969	2,415,213	7,632,182	$332,080,587,191	$136,812,805,015	$817,142,119,042	$336,651,733,688	$473,464,538,703
2049	4,178,175	72.17%	1,162,599	3,015,575	0.78	4,801,536	2,355,458	7,156,993	$318,816,288,823	$127,522,417,197	$784,503,002,834	$313,791,116,474	$441,313,533,671
2050	4,194,888	74.14%	1,084,906	3,109,982	0.74	4,480,662	2,303,135	6,783,796	$309,383,971,817	$120,145,254,025	$761,293,144,134	$295,638,321,702	$415,783,575,727
2051	4,211,667	75.64%	1,026,057	3,185,610	0.71	4,237,614	2,260,447	6,498,061	$303,405,816,857	$114,391,956,367	$746,582,852,715	$281,481,330,836	$395,873,287,203
2052	4,228,514	76.77%	982,248	3,246,266	0.69	4,056,684	2,227,529	6,284,213	$300,404,300,949	$109,961,462,223	$739,197,100,087	$270,579,328,391	$380,540,790,614
2053	4,245,428	77.62%	950,174	3,295,254	0.67	3,924,219	2,203,437	6,127,656	$299,891,917,457	$106,576,608,601	$737,936,291,270	$262,250,306,558	$368,826,915,159
2054	4,262,410	78.25%	927,104	3,335,305	0.66	3,828,940	2,186,800	6,015,740	$301,421,760,586	$104,000,281,020	$741,700,736,722	$255,910,803,858	$359,911,084,877
2055	4,279,459	78.72%	910,859	3,368,600	0.65	3,761,848	2,176,196	5,938,043	$304,609,884,694	$102,039,113,798	$749,545,671,326	$251,085,010,358	$353,124,124,156
2056	4,296,577	79.06%	899,740	3,396,837	0.64	3,715,927	2,170,337	5,886,264	$309,140,228,727	$100,540,487,134	$760,693,371,810	$247,397,378,453	$347,937,865,586
2057	4,313,763	79.31%	892,448	3,421,315	0.63	3,685,810	2,168,139	5,853,950	$314,760,237,660	$99,386,661,180	$774,522,382,556	$244,558,188,746	$343,944,849,926
2058	4,331,018	79.50%	887,999	3,443,020	0.63	3,667,434	2,168,729	5,836,164	$321,272,439,249	$98,488,264,004	$790,546,788,713	$242,347,526,032	$340,835,790,036
2059	4,348,342	79.63%	885,655	3,462,688	0.63	3,657,754	2,171,423	5,829,178	$328,524,998,867	$97,778,238,609	$808,392,974,739	$240,600,384,893	$338,378,623,502
2060	4,365,736	79.73%	884,868	3,480,868	0.63	3,654,503	2,175,695	5,830,198	$336,402,790,649	$97,206,689,348	$827,777,653,396	$239,193,988,395	$336,400,677,743
					TOTALS	**402,786,203**	**56,187,152**	**458,973,355**	**$15,737,900,707,221**	**$8,838,243,888,235**	**$38,725,845,560,464**	**$21,748,038,331,723**	**$30,586,282,219,958**

BIBLIOGRAPHY

Autonomous Vehicles | Self-Driving Vehicles Enacted Legislation. (2018, January 2). Retrieved February 28, 2018, from http://www.ncsl.org/research/transportation/autonomous-vehicles-self-driving-vehicles-enacted-legislation.aspx

Bansal, P., & Kockelman, K. M. (2017). Forecasting Americans' long-term adoption of connected and autonomous vehicle technologies. *Transportation Research Part A: Policy and Practice*, 95, 49-63.

Blanco, M., Atwood, J., Russell, S., Trimble, T., McClafferty, J., & Perez, M. (2016, January). Automated Vehicle Crash Rate Comparison Using Naturalistic Data. *Virginia Tech Transportation Institution*. Retrieved February 25, 2018, from https://www.vtti.vt.edu/PDFs/Automated%20Vehicle%20Crash%20Rate%20Comparison%20Using%20Naturalistic%20Data_Final%20Report_20160107.pdf

Blincoe, L., Miller, T., Zaloshnja, E., & Lawrence, B. (2015). *The economic and societal impact of motor vehicle crashes, 2010 (revised).* Washington, D.C: U.S. Dept. of Transportation, National Highway Traffic Safety Administration.

Blincoe, L., Seay, E., Zaloshnja, E., Miller, T., Romano, E., Lutcher, S., & Spicer, R. (2002). *The economic impact of motor vehicle crashes, 2000.* Washington, D.C: U.S. Dept. of Transportation, National Highway Traffic Safety Administration.

Boudette, N. E. (2017, February 15). U.S. Traffic Deaths Rise for a Second Straight Year. Retrieved February 20, 2018, from https://www.nytimes.com/2017/02/15/business/highway-traffic-safety.html

Brandewindere, M. (2008, June 8). S-Shaped Market Adoption Curve. Retrieved December 30, 2017, from http://www.clear-lines.com/blog/post/S-shaped-market-adoption-curve.aspx

Critical Reasons for Crashes Investigated in the National Motor Vehicle Crash Causation Survey (2015, February). *National Highway Traffic Safety Administration*. Retrieved November 16, 2017, from https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812115

Fagnant, D. J., & Kockelman, K. (2015). Preparing a nation for autonomous vehicles: Opportunities, barriers and policy recommendations. *Transportation Research Part A: Policy and Practice*, 77, 167-181.

Faheem, A. M. (2017). Autonomous vehicles: Safety, sustainability, and fuel efficiency. *I-Manager's Journal on Future Engineering and Technology, 12*(4), 1-7.

Fatality Analysis Reporting System (FARS) Encyclopedia. *National Highway Traffic Safety Administration.* Retrieved November 15, 2017, from https://www-fars.nhtsa.dot.gov/Main/index.aspx

Foellmi, R., Wuergler, T., & Zweimüller, J. (2014). The macroeconomics of model T. *Journal of Economic Theory*, 153, 617-647.

Haboucha, C., Ishaq, R., & Shiftan, Y. (2017). User preferences regarding autonomous vehicles. *Transportation Research Part c-Emerging Technologies*, 78, 37-49.

H.R. 3388: SELF DRIVE Act. (n.d.). Retrieved February 28, 2018, from https://www.govtrack.us/congress/bills/115/hr3388/summary

Joscelyn, K. B., & Treat, J. R. (1976). *Tri-level study of the causes of traffic accidents: Interim report II. Final Report.*

Kalra, N., & Groves, D. G. (2017). *The enemy of good: Estimating the cost of waiting for nearly perfect automated vehicles.* RAND Corporation.

Lavasani, M., Jin, X., & Du, Y. (2016). Market penetration model for autonomous vehicles on the basis of earlier technology adoption experience. *Transportation Research Record*, 2597(2597), 67-74. doi:10.3141/2597-09

Litman, T. (2017, September 8). Autonomous Vehicle Implementation Predictions Implications for Transport Planning. *Victoria Transport Policy Institute*. Retrieved November 19, 2017, from https://www.vtpi.org/avip.pdf

McCormick, C. (2017, October 02). What's in the AV START Act? Retrieved February 28, 2018, from https://medium.com/@cfmccormick/whats-in-the-av-start-act-8f91780e8f8b

National Center for Statistics and Analysis. (2017, October). Summary of motor vehicle crashes (Final edition): 2015 data. (Traffic Safety Facts. Report No. DOT HS 812 376). Washington, DC: National Highway Traffic Safety Administration.

National Motor Vehicle Crash Causation Survey: Report to Congress (DOT HS 811 059) (July, 2008) by U.S. Department of Transportation National Highway Traffic Safety Administration.

Office of Management and Budget. (2018, February 2). 2018 Discount Rates for OMB Circular No. A-94.

Restating the National Highway Transportation Safety Administration’s National Motor Vehicle Crash Causation Survey for Automated Vehicles (2014). *Casualty Actuarial Society Automated Vehicles Task Force*. Retrieved February 25, 2018, from http://www.casact.org/pubs/forum/14fforum/CAS%20AVTF_Restated_NMVCCS.pdf

Road to Zero Coalition. (n.d.). Retrieved February 28, 2018, from http://www.nsc.org/learn/NSC-Initiatives/Pages/The-Road-to-Zero.aspx

Singh, S. (2015, February). Critical reasons for crashes investigated in the National Motor Vehicle Crash Causation Survey. (Traffic Safety Facts Crash Stats. Report No. DOT HS 812 115). Washington, DC: National Highway Traffic Safety Administration.

USDOT Releases 2016 Fatal Traffic Crash Data. (2017, October 06). *National Highway Traffic Safety Administration*. Retrieved November 15, 2017, from https://www.nhtsa.gov/press-releases/usdot-releases-2016-fatal-traffic-crash-data

U.S. Federal Highway Administration. (2017, May 04). FHWA Forecasts of Vehicle Miles Traveled (VMT): Spring 2017.

U.S. Federal Highway Administration, Vehicle Miles Traveled [TRFVOLUSM227NFWA], retrieved from FRED, Federal Reserve Bank of St. Louis; https://fred.stlouisfed.org/series/TRFVOLUSM227NFWA, March 4, 2018.

Academic Vita
PARKER M. CAHN

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EDUCATION & AWARDS:

The Pennsylvania State University: Schreyer Honors College — **University Park, PA**

Smeal College of Business: Bachelor of Science in Finance, Two-Piece Sequence in Organizational Leadership — *Class of 2018*

College of Liberal Arts: Bachelor of Science in Economics, Honors Economics Program

- Brian T. Geffert and Irene N. Lane Scholarship Recipient
- Anthony Buzzelli Sapphire Scholarship Recipient
- Berquist Trustee Scholarship Recipient
- Highest Ranked North American Team 2017 University of Florida Heavener International Case Competition
- 1st Place 2015 KPMG International Case Competition (PSU)
- 1st Place 2015 PwC Tax Challenge Case Competition (PSU)
- 2nd Place 2016 Deloitte Case Competition (PSU)
- 2nd Place 2015 KPMG Atlantic Regional Case Competition (Washington, D.C.)

PROFESSIONAL EXPERIENCE:

Deloitte Consulting — **Pittsburgh, PA**

Strategy and Operations Summer Scholar — *May 2017 – Aug 2017*

- Worked in a team of 4 to analyze a Fortune 200 biotech company's European financial operations to develop a business case and implementation roadmap for migrating select positions across 25 countries and 95 facilities to a single shared service center
- Responsible for modeling $10 million in implementation costs including $6 million in severance and $4 million in facility build-out
- Developed employee communication strategy to minimize the loss of key employees prior to the shared service center's go-live dates
- Produced materials and assisted in hosting a 2-day workshop with 30 of the client's European finance heads in Frankfurt, Germany
- Conducted full in-depth analyses of labor cost savings, the inclusion of additional rolls in the migration, and European labor laws

University Professional and Continuing Education Association (UPCEA) — **State College, PA**

Market Research and Consulting Intern — *May 2016 – Aug 2016*

- Published a white paper to UPCEA's 400 university subscribers about the effect of autonomous vehicles on the job market
- Created individualized reports recommending programs clients should offer based on regional occupation and industry growth
- Attracted new clients by composing a report investigating university enrollment declines in Michigan, Florida, and California
- Built a report benchmarking continuing education programs utilizing the 165 university responses to UPCEA's management survey

Level Interactive — **Pittsburgh, PA**

Digital Marketing Intern — *Jul 2015 – Aug 2015*

- Analyzed over 50,000 entries of call center data to observe inconsistencies with the callers' speed to lead time based on the source of the leads' contact information and presented these findings to executive staff resulting in changes to call center policy
- Projected from four years of historical data the expected impressions, clicks, and conversions for proposed ad spend campaigns
- Managed a client's 36 location business listings campaign across 20 unique online directories for organic search engine optimization

LEADERSHIP EXPERIENCE:

Nittany Consulting Group — **University Park, PA**

Executive Board | Executive Director (Co-President) — *Dec 2016 – May 2018*

- Overhauled organization by determining new structure, membership requirements, disciplinary processes, and election system
- Secured over $10,000 of corporate sponsorship to help fund our annual public outreach events and continued education programs
- Oversaw the organization's twelve-week training program, 6 pro-bono consulting engagements, and networking opportunities
- Lead a revitalized online and in person marketing strategy that substantially increased the diversity of 130 new applicants

Senior Consultant — *Apr 2015 – May 2018*

- Worked with a team of 3 to write a preliminary multimillion dollar investment plan involving developing land in West Africa
- Developed a new marketing strategy for a local restaurant aimed at students to help drive increased traffic and sales
- Composed the curriculum for the Fall 2016 Consultant Training Program, a twelve-week class focused on the skills of consulting

Sapphire Leadership Academic Program — **University Park, PA**

Executive Board | Involvement Captain — *Dec 2015 – Dec 2016*

- Managed a team of three chairs to accomplish the goal of building meaningful and valuable connections between members
- Revamped Sapphire's internal mentorship program by organizing over 10 events before and after mentorship pairings
- Created Sapphire's first ever alumni and involvement databases to increase value of the program to its members

Distinguished Sapphire Leader — *May 2014 – May 2018*

- Recruited into a 50-member cohort, representing the top 5% of the Smeal incoming class academically
- Responsible for completing over 24 professional and leadership development service hours each semester
- Engaged in academically rigorous Sapphire courses to replace general courses of the business curriculum

Presidential Leadership Academy — **University Park, PA**

Class of 2018 | Member — *Mar 2015 – May 2018*

- Selected to be one of 30 students to participate in a 3-year academic and extra-curricular program within the honors college
- Applied critical thinking skills in weekly discussions led by the President of the University and Dean of the honors college
- Published a 59-page policy brief with five other classmates that sought to create a fairer system for CEO compensation
- Received fully funded trips across the United States to learn about local leadership problems and solutions in action today

ADDITIONAL EXPERENCE:

Penn State IFC/Panhellenic Dance Marathon — **University Park, PA**

Dancer | Sapphire THON Fundraising Committee — *Aug 2014 – Feb 2018*

Penn State Economics Department — **University Park, PA**

Teaching Assistant | Intermediate Macroeconomics — *Jan 2016 – Dec 2017*

Smeal College of Business — **University Park, PA**

New Student Orientation | Ambassador Intern — *May 2016 – Aug 2016*

Fred Brand Jr. Excellence in Teaching Award Selection Committee — **University Park, PA**

Student Representative — *June 2016*