SAFETY ASPECTS OF BICYCLISTS IN A
CONNECTED VEHICLE ENVIRONMENT

by

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THESIS

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ABSTRACT

The revival in the number of bicyclists, bike infrastructure investments and bike policies in the U.S. in the last two decades has escalated the importance of bicycling as a mode of transportation. With the proliferating role of the bicycle mode, bike fatalities continue to grow, too. In response to the increase in fatalities and crashes caused by human driven vehicles, the automobile industry and governments seek to develop autonomous vehicles that can address most of the human related crash causes. While increasing safety remains the primary goal of autonomous vehicles (AV) innovation, the difficulty of bicyclist and pedestrian detection using sensor based techniques, poses a potential threat to AV adoption. Connected vehicle technology for AVs offers an array of safety and non-safety applications for vehicles. Hence, this research examines the necessity to bring bicyclists into the same connected environment as AVs and the options available to accomplish this connectivity. The research also provides insight into bicyclists' perception towards AVs and their opinion on buying a device to provide this connectivity with AVs. The survey results indicate that most of the bicyclists consider safety as their top priority while bicycling; as a result, they invest in safety equipment for themselves and their bicycle. Although most of the bicyclists are skeptical about the operation of AVs on roads, they express a willingness to opt for a bike-mountable device that communicates with AVs for detection of bicyclists. Based on a logistic regression model using the survey data, the frequency of bicycling, investment in some types of safety equipment and the price of the device influence the willingness to adopt this device.

ACKNOWLEDGEMENTS

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(Sanskrit shloka written in Kannada language. It is a holy verse for a teacher. Translation is given below)
"Salutation to the noble Guru, who is Brahma, Vishnu and Maheswara, the direct Parabrahma, the Supreme Reality"

I would first like to thank my thesis advisor Dr. Stephen P. Mattingly for his continuous support to my study and research, for his patience, motivation, exuberance, and immense knowledge. Words cannot describe his influence in my life. Had I been not given strength, scope and motivation by him, none of this would have been accomplished. Prof. Mattingly always kept his office door open, so that students can find the light of hope whenever bounded by the darkness. He constantly steered me in the right direction by giving invaluable advice, whenever he thought I needed it. This research was successfully conducted only because of him.

I would also like to thank the bicyclists, representatives and members of bike communities who were involved in the survey for this research project: BikeDFW, Bike Friendly Richardson, Bike Austin and Michigan Fitness Foundation. Without their passionate participation and input, the survey could not have been successfully conducted.

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Author

Ajaykumar Patil

DEDICATION

“Nothing of me is original. I am the combined effort of everybody I've ever known“

- Chuck Palahniuk

I dedicate this work to my mother, family, friends and teachers because of whom I am able to contribute to the society today. I thank and dedicate this work to all the people who strived and are striving for the betterment of this world. I thank all the people for using renewable energy sources and, eco-friendly techniques and products that counter global warming. I thank and dedicate this work to all the people for using bicycle as a mode of transportation and I hope that the trend continues to grow. I thank and dedicate this work to all the people who strived and are striving to protect Arctic and Antarctic region. I would like to thank and dedicate every accomplishment of my life to my mother, Ms. Renuka Patil (Kallur), and to my uncles, Dr. Ravi Kallur and Dr. S. S. Injaganeri, for inspiration in every endeavor of my life. The amount of love I receive from my friends has been the driving force of my journey. There are very few artists who inspire directly or indirectly to our lives through their work: A. R. Rahman, Christopher Nolan and Hans Zimmer are few of them from whom I have fetched lot of inspiration and tranquility. Lastly, I would like to mention a quote by Dan Brown that I have been hugely inspired by.

“*Sometimes all it takes is a tiny shift of perspective to see something familiar in a totally new light”*

- Dan Brown

LIST OF ILLUSTRATIONS

LIST OF TABLES

TABLE OF CONTENTS

INTRODUCTION

Emerging Importance of Bicycling

The bicycle is gaining popularity in recent times due to an awareness of the economic, health and environmental benefits associated with it. Increasing greenhouse gas emissions, lifecycle costs involved in gasoline powered vehicles, healthy lifestyle concerns and obligations to cut carbon emissions have motivated people to shift to more ecofriendly modes of transportation. Statistics show that the number of bicycle users has increased considerably in the last two decades. The surveys conducted by various agencies show that between 1977 and 2009, the number of bike trips in the U.S. more than tripled, whereas the bike share of total trips doubled (*1*). Since 2000, the number of daily bike commuters has almost doubled (*1*). Although two-thirds of the bike trips made in the U.S. are for recreational purposes (*2*), the National Household Travel Survey (NHTS) data between 2001 and 2009 indicate a significant upward growth in the utilitarian use (non-recreational trips) of bicycles. This trend indicates a change in the public's perspective of bicycling beyond recreation (*1*). This progressive relationship connects the extent of bicycling with governmental interventions (e.g. bike infrastructure, incorporation of bikes with public transport, education and marketing programs and bicycle access programs) (*3*). The formation of government policies for bicyclists and investment in bike infrastructure has played a key role in the nationwide upward trend in utilitarian bicycling.

When motor vehicles started gaining more popularity and became the mainstream mode of transportation during the 1890s, they demanded a high budget to provide and maintain a robust infrastructure. At the same time, the bicycle began to lose its luster and became an outdated transportation mode. After realizing the consequences of excessive growth and vehicle usage, and by observing the success of European countries in bicycling, the U.S. government's intervention seemed critical in reviving bicycling and promoting this sustainable and eco-friendly mode of transportation. In the U.S., the federal government promoted cycling and supported a remarkable growth in bicycle-related programs and policies over the past two decades (*1*). During the Intermodal Surface Transportation Efficiency Act (ISTEA), the average federal funding for cycling and walking ascended from $5 million per year to $150 million per year (*1*). Between 1999 and 2005, under the Transportation Equity Act for the 21st century (TEA21), funding rose to $360 million per year (*1*). The passage of the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) enlarged funding to almost $1 billion per year during 2006-2009 (*1*). This indicated the recognition of importance of cycling as a mode of transportation and also encouraged state and local governments to include bike infrastructure in their overall transportation infrastructure plans.

Between 2000 and 2012, the number of people traveling to work by bicycle rose from 488,000 to 786,000 (*4*). Data from the Rails to Trails Conservancy shows that between 1990 and 2010, bike trails expanded from 2044 miles to 15,964 miles in the U.S., which is almost 800% growth (*1*). The City of Portland, Oregon, exemplifies the success of bike infrastructure investments. A survey conducted in 2008 found that 18% of Portland's residents' primary or secondary mode of transportation to work is bike. This compares favorably with northern European countries where the mode share for cycling is often significantly higher than the U.S. (*3*). The City of Portland's success infers that even though American residents rely on cars, providing a proper suite of bike policies, infrastructure and programs may lead to a positive growth in the cycling trend (*1*)(*3*).

To further bolster the impact of cycling infrastructure and policies, communities with proper bike infrastructure that fully accommodates bicyclists' safety appear more likely to have higher levels of recreational bicycling, which may also lead to a higher level of utilitarian bicycling (*2*). The merging of mixed land-use and bike infrastructure can enhance both the physical and social environment because a shorter commute distance, increases the likelihood of bike-to-work trips (*2*). In the City of Portland, between 1991 and 2008, a significant percentage rise in bike users can be related to a 247% increase in bikeway mileage from 79 miles to 274 miles. The City of Portland's cycling infrastructure is highlighted by facilities such as bike boxes at intersections, bike parking racks at public buildings, allowing bikes and providing bike racks in transit buses and trains, and special bicycle-only signals at several intersections and loop detectors for bicycles at all actuated traffic signals on bike routes. In addition to the propagation of bike infrastructure, education and marketing programs such as city-wide and neighborhood bicycle maps and events like "Bike Sundays" and "SmartTrips" have also contributed to this increase (*3*). However, investment in bike infrastructure and environmental factors does not necessarily contribute towards the increase in bicycling, rather, cycling is largely dependent on personal factors (*5*). But, improving the built and transportation environment for cycling can certainly alter the public's perception of cycling, which can then increase the number of cycling trips and cyclists (*5*). Hence, identifying the factors hindering bicycle usage, and providing appropriate bike infrastructure, may enhance the cycling trend.

Even though bike infrastructure and policies are aiding in improving the cycling environment, the safety of bicyclists is threatened by vehicles that share the road with them. According to crash statistics published by the National Highway Traffic Safety Administration (NHTSA), pedalcyclist fatalities caused due to motor vehicle traffic crashes were approximately two percent of the total fatalities in 2013 (*6*). The NHTSA defines pedalcyclists as "bicyclists and other cyclists including riders of two-wheel, nonmotorized vehicles, tricycles, and unicycles powered solely by pedals". The number of pedalcyclist fatalities in 2010 were 623 whereas in 2013, 743 pedalcyclists were killed and approximately 48,000 were injured in motor vehicle traffic crashes (*6*). Pedalcyclist fatalities have increased by 19% in 2013 as compared to pedalcyclist fatalities in 2010. In 2013, 68% of pedalcyclist were killed in urban areas and 32% were killed in rural areas (*6*). Hence, improving the safety of both vehicles and bicyclists appears essential. The potential ways to tackle this issue include vehicles using sensors to detect bicyclists and alert human drivers of a potential hazard or by establishing communication between bicyclists and vehicles. The next section discusses the safety applications for vehicles that may potentially avoid a large number of vehicle crashes.

Emergence of Autonomous Vehicles

According to the NHTSA, over 6 million crashes occur in the U.S. and approximately 32,000 fatalities have been reported every year since 2012 (*7*). Human driving errors contribute to approximately 90% of all crashes; the role of human error in crashes has prompted the drive towards an autonomous vehicle (AV) (*8*). A research study focused on driver related issues, conducted by the NHTSA, reveals that 41% of crashes are due to recognition error (includes driver's inattention, internal and external distractions, and inadequate surveillance) and 33% of the crashes are due to decision error (includes driving too fast for conditions, too fast for the curve, false assumption of others' actions, illegal maneuver and misjudgment of gap or others' speed) (*8*). Another report from the NHTSA reveals that passive safety devices such as seatbelts and frontal air bags saved approximately 15,198 lives in 2014 (*7*). This study focuses beyond passive safety applications and investigates the potential of active safety applications.

A report published by the NHTSA estimates that, approximately 80% of crashes can be avoided using vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications (*9*). AVs are currently being developed to address both safety and non-safety applications. An AV can easily detect another AV due to the exchange of basic safety message (BSM) transmitted from a dedicated short-range communication (DSRC) device fitted inside the AVs. The DSRC device transmits BSM every one-tenth of a second for several hundred feet in a 360 degree pattern, and communicates with all the surrounding DSRC equipped AVs (*10*). Although AVs are capable of navigating by themselves, sharing host vehicle navigation information through a DSRC with surrounding vehicles bridges the link between the vehicles and thus enhances the safety of the vehicle navigation environment. The connection established between AVs would allow AVs talk to each other and predict each other's trajectories in real-time to check for any potential hazards along their path. Hence, they are known as connected vehicles (CV) (*11*). If the vehicles are not equipped with a DSRC device, AVs detect these vehicles using AV mounted sensors, cameras and radar applications (*12*, *13*). The United States Department of Transportation (USDOT) plans to connect all AVs using DSRC communications so that safety and non-safety applications can be used (*14*). A brief history of CVs and AVs is provided in Appendix A.

According to the NHTSA, AVs are categorized into 5 levels, and each are briefly discussed below. A level 4 AV requires no human driver's assistance whereas level 1 to level 3 AVs require a human driver's assistance and alertness.

"No-Automation (Level 0): The driver is in complete and sole control of the primary vehicle controls – brake, steering, throttle, and motive power – at all times.

Function-specific Automation (Level 1): Automation at this level involves one or more specific control functions. Examples include electronic stability control or pre-charged brakes, where the vehicle automatically assists with braking to enable the driver to regain control of the vehicle or stop faster than possible by acting alone.

Combined Function Automation (Level 2): This level involves automation of at least two primary control functions designed to work in unison to relieve the driver of control of those functions. An example of combined functions enabling a Level 2 system is adaptive cruise control in combination with lane centering.

Limited Self-Driving Automation (Level 3): Vehicles at this level of automation enable the driver to cede full control of all safety-critical functions under certain traffic or environmental conditions and in those conditions to rely heavily on the vehicle to monitor for changes in those conditions requiring transition back to driver control. The driver is expected to be available for occasional control, but with sufficiently comfortable transition time. The Google car is an example of limited self-driving automation.

Full Self-Driving Automation (Level 4): The vehicle is designed to perform all safety-critical driving functions and monitor roadway conditions for an entire trip. Such a design anticipates that the driver will provide destination or navigation input, but is not expected to be available for control at any time during the trip. This includes both occupied and unoccupied vehicles." (*15*).

Although a level-4 AV has many social and technical challenges to overcome, the potential benefits of AVs are driving the zeal of automobile manufacturers and researchers. Progress in developing fully AVs is slowly proceeding. Public acceptance, reliable technology and insurance policies represent a few of the key factors that currently hinder the widespread development and adoption of AVs (*14, 16, 17*).

Intersection of Bicyclists Safety and Autonomous Vehicles

An AV relies entirely upon on-board sensors, cameras, thermal imagery, infrared sensors, radar and LIDAR to detect bicyclists and pedestrians (*13,14*). An AV's potential to judge a situation and drive safely without receiving any assistance from a human driver under any circumstances also depends on the processors' capability and the sensors' functionality. However, the current technology available for AVs to analyze the street environment and drive safely under all circumstances needs further improvements, which can be addressed using DSRC communications (*14*). Although pedestrian safety remains critical, this research focuses on the safety of bicyclists in a CV environment AVs share roads more often with bicyclists than with pedestrians. According to the NHTSA, approximately 56% of pedalcyclist death occurred between 3 p.m. and 11.59 p.m. in 2013 (*4*, *6*) hence, AVs must be fully effective in detecting bicyclists during any time of the day (especially low/no light conditions) and any type of weather. Successful mastery of the detection requirements appears likely to enhance public trust of AVs; however, this on-going concern regarding the interaction of AVs with pedestrians and bicyclists poses a significant obstacle to public support (*9*).

A bike-mountable DSRC device that can be used by bicyclists to communicate with AVs (bicycle-to-vehicle, B2V) seems to be one of the possible solutions to this problem. A bicyclist can only be brought into the V2X (vehicle-to-other) communication system when a vehicle awareness device (VAD) used by a bicyclist, transmits a basic safety message (BSM) to surrounding DSRC equipped vehicles (B2V) and roadside equipment (RSE) (bicycle-to-infrastructure, B2I). The USDOT defines a VAD as, "an aftermarket electronic device, installed in a vehicle without connection to vehicle systems, which is capable of only sending the basic safety message (BSM) over a DSRC wireless communications link. VADs do not generate warnings. They may be used in any type of vehicle." (*18*). A bike-mountable DSRC device can be either in the form of a VAD (one-way communication: bike hosted device transmitting BSM to nearby vehicles) or an aftermarket safety device (ASD) (two-way communication: bike hosted device receives and transmits BSM, and also bicyclist is alerted in audio/visual form) (*18*).

While the concept of using a bike-mountable DSRC device for detecting bicyclists in the initial phase of a V2X operated vehicle environment promises to prevent vehicles from colliding with bicyclists, the DSRC device must be affordable and acceptable to the public. The device manufacturers still must make technological enhancements so that the B2X (bicycle-to-other) communication device could be available at an affordable price. Public acceptability requires both interest and the willingness to bear the cost of the device. Many people may be skeptical about this and state that AVs should be capable of detecting bicyclists under all circumstances and no cost should be incurred from the bicyclists. Although this statement may hold true from society's perspective, this research attempts to capture the views of the bicycling public. This sub-population "passively" support the operation of AVs during the initial phase of usage of V2X operated vehicles, by seeking an extra layer of safety through DSRC. Since the research to develop fully efficient AV continues, the detection and avoidance of all roadway hazards such as bicyclists remains critical.

The prediction of a bicyclist's behavior in real-time poses one of the major challenges to AVs. Sometimes, certain instantaneous reactions or detection of multiple bicyclists may put the artificial intelligence (AI) of an AV into a complicated situation (*19*). Hence, deploying a bike-mountable DSRC device not only includes bicyclists in V2X communications, but also helps AVs to predict a bicyclist's behavior in real-time.

THESIS CONTRIBUTION

To the best knowledge of the author, the detection of bicyclists by AVs relies entirely upon vehicle mounted on-board sensors, cameras, radar, LIDAR, thermal imagery or infrared sensors, which may be supplemented by V2V and V2I data. The efficient detection of bicyclists by vehicles using sensor based detection techniques depends on many factors such as type and condition of processors and sensors equipped, weather conditions, and bicyclist behavior. At this time, no device in the marketplace connects bicyclists within the V2V and V2I communication system. The author believes that currently available biking gadgets, which are known as cyclo-computers and used for navigation, can be modified to enable DSRC communication and include bicyclists in V2X communications. A bike-mountable DSRC device may be able to reduce the reliance on or enhance the capabilities of on-board sensor arrays. As many bicyclists use biking gadgets such as cyclo-computers for navigation, the study hypothesizes that these bicyclists may have a willingness to use a bike-mountable DSRC device. This research uses a survey to explore bicyclists' opinions about AVs and their interest in a bike-mountable DSRC device. This study uses the survey results to estimate a binary logit model and assesses the willingness to pay for the device as well as briefly describe potential mode driven applications.

METHODOLOGY

The study uses an online survey data to determine bicyclists' opinion about using a bike-mountable DSRC device while controlling for the influences of demographic characteristics, physical-environment factors, bike infrastructure, concern towards AVs and price of the bike-mountable DSRC device. The sample is drawn from the responses of bike community members.

Survey Design, Sampling and Administration

Because of the high cost of a bike-mountable DSRC device, the target market appears to be bicycling enthusiasts. The survey seeks responses from this sub-population; therefore, the author solicits bike communities, like BikeDFW and Bike Friendly Richardson, to share the survey with their members. The researchers have received eighty valid survey responses. The survey organizes the questions into the following categories: socio-demographic data, bike trips information, accessories used by bicyclists, level of safety on roads, bike infrastructure properties, bicyclist's opinion on AVs, and price of bike-mountable DSRC device. The complete survey questionnaire is displayed in Appendix B**.**

The survey results show that the response pool has 37% between 36 and 50 years, 49% above 50, 11% between 26 and 35 and 3% between 18 and 25 years. While most of the respondents regularly ride, only 23% bicycle daily, 42% ride 3-5 days per week, 27% ride 1 or 2 days per week and 8% of the respondents rarely use the bicycle (Figure 1). A majority (76%) of the respondents typically use the bicycle for a non-work purpose (recreational/park/exercise/school) whereas 24% typically use their bicycle for work trips.

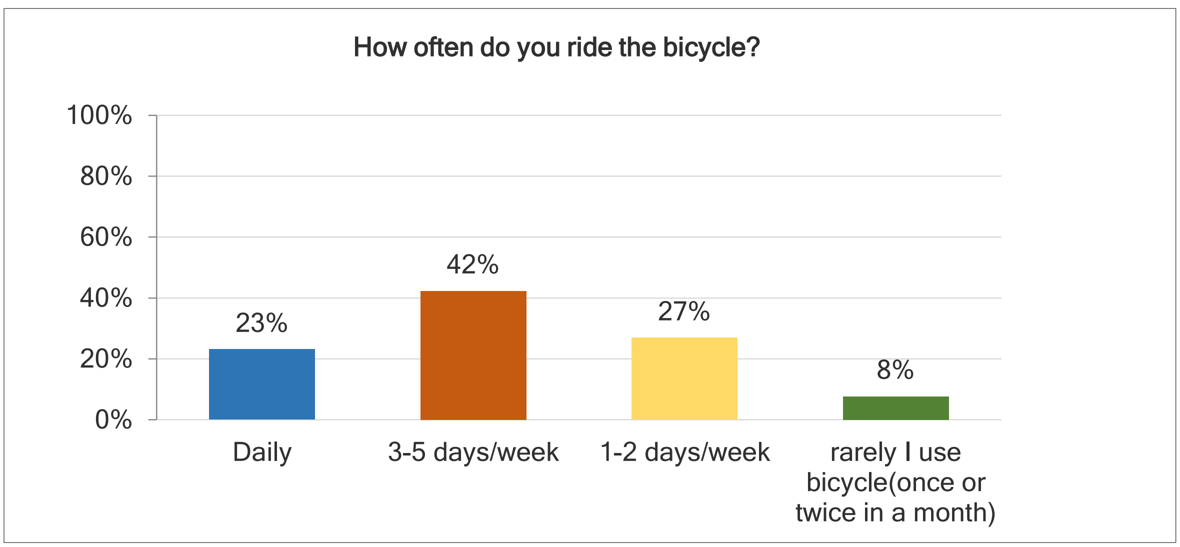

FIGURE 1. Bike Use Frequency

Figure 2 shows high safety awareness amongst the bicyclists with 95% choosing to use a helmet and 90% using a front or rear light. The high percentage of bicyclists using a front or rear light and high contrast clothes while cycling may indicate that they often cycle during low light conditions. Perhaps most importantly, 47% of those surveyed already use other electronic tools like GPS navigation devices; this indicates that a significant interest already exists in the current electronic devices available in the marketplace.

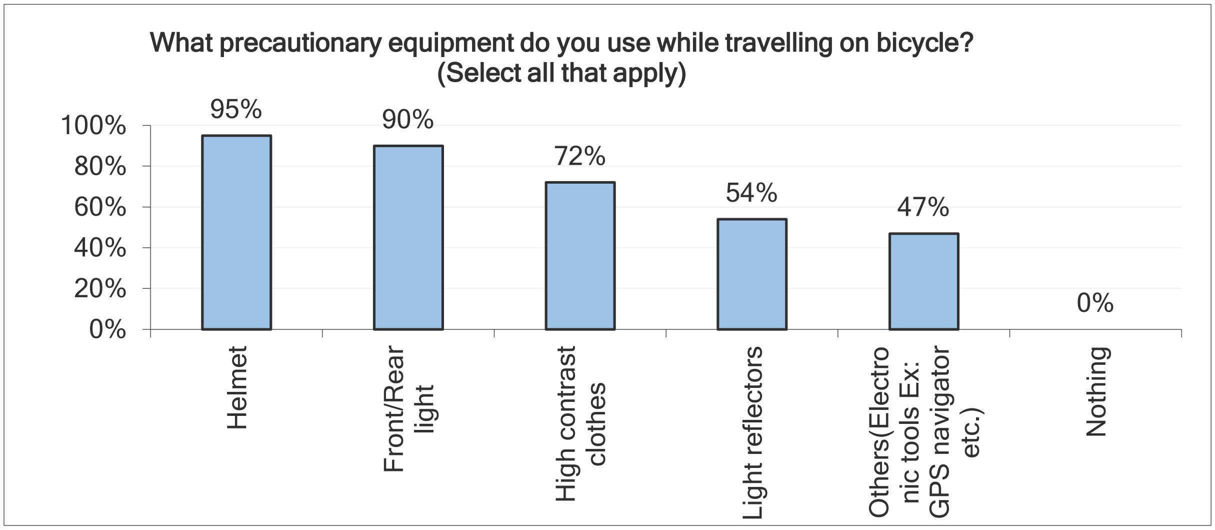

FIGURE 2. Type of Safety Equipment Used.

Roadway characteristics and conditions may impact bicyclists' perception of safety. About half of the respondents typically use local or collector roads with 41% using roads with a speed limit between 20-35 mph and 8% using roads with a speed limit of less than 20 mph. Most of the remaining respondents use major and minor arterials with 44% on roads with a speed limit between 35-45 mph. The remaining 8% use roads with a speed limit greater than 45 mph. Due to the types of organizations used for recruitment, the respondents demonstrate a higher level of confidence than expected of typical bicyclists. When bicycling, almost half (46%) of the respondents feel safe (36%) or very safe (10%). Most of the remaining respondents (51%) overall feel safe but still have a slight fear at the same time; only 1% of respondents indicate that they frequently get afraid or feel totally unsafe when bicycling. The roadway and traffic characteristics that negatively impact safety perceptions while bicycling are shown in Figure 3.

Over 70% of the respondents report that high speed traffic, high traffic volumes and roads with narrow travel lanes or no bike lanes make them feel unsafe while bicycling. A far lower percentage of the respondents feel insecure due to poor visibility (36%) and in intersections: crossing (24%) and vehicles making right turns (26%).

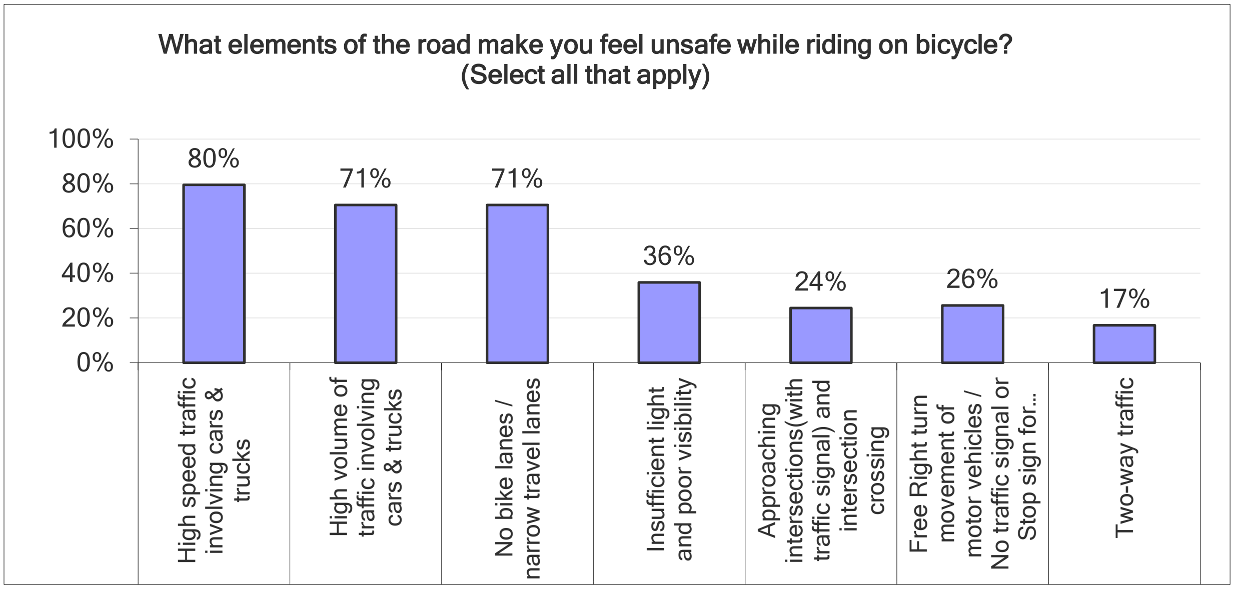

FIGURE 3. Road Elements Impacting Bicyclists' Safety Perceptions.

When bicyclists consider their interest in a bike-mountable DSRC device without any pricing information, more than 45% of bicyclists respond that they want to know about the other device features and 5% of them state that they would definitely purchase the device. The study derives the dependent variable from the response to the survey question that asked bicyclists to make a purchase decision at a fixed price tag, e.g. "Will you buy the device if it costs $1000?". The study structures the survey questionnaire for pricing so that four candidate prices may be presented to each respondent. The first question starts at the highest price ($1000) and proceeds to lower the price in $250 increments until the respondent decides to purchase the device or the respondent refuses to purchase at the lowest price ($250). The study assumes that if a bicyclist responds yes to a price that is greater than $250, then the response for all lower prices will also be yes. At all prices, the respondents may also opt to “maybe purchase” depending on future trends or the device’s other features. Currently, the features that a DSRC device manufacturer or cyclo-computer manufacturer will offer in a bike-mountable DSRC device are not known. Hence, for the analysis, responses of bicyclists definitely buying the device and bicyclists who showed interest in the DSRC device are merged for each respective pricing option, and this becomes the dependent variable for the current research. Although the new dependent variable does not directly assure the purchase of a DSRC device, it does provide an indication of interest amongst bicyclists for the DSRC device.

Variables

The author uses the variables categorized under bike riding frequency, safety equipment used, opinion on AVs and price of the bike-mountable DSRC device to perform binary logistic regression. This analysis treats each choice provided for the questions in the survey as a separate independent variable. For categorical questions with single choice answers, the number of independent variables is calculated by the number of choices given for a respective survey question subtracted by 1. The same procedure is followed when dealing with “select all that apply” questions but without reserving a reference variable. The variables included in the final model are shown in Table 1. The variables in the final model characterize a respondent’s frequency of bicycle use, his or her support of AVs, use of safety equipment and DSRC price. The sample data collected by the survey is explained by the model which consists of variables “price”, “3-5 days/week” (3-5D), “1-2 days/week” (1-2D), “front or rear light” (FRL), “high contrast clothes” (HCC), “light reflectors” (LRef), “others” (OET) and “yes, I do support AVs even if the detection of bicyclists and pedestrians requires more improvement” (YIDS).

TABLE 1. Description of Final Model Variables

Name	Definition	Coding	Type
3_5D	Bike usage frequency of 3 to 5 days per week	"1", if bicyclist's bike usage frequency is 3-5 days/week or else "0"	Categorical
1_2D	Bike usage frequency of 1 to 2 days per week	"1", if bicyclist's bike usage frequency is 1-2 days/week or else "0"	Categorical
FRL	Bike safety equipment - front/rear light	"1", if bicyclist uses front/rear light or else "0"	Categorical
HCC	Bike safety equipment – high contrast clothes	"1", if bicyclist uses high contrast clothes or else "0"	Categorical
LRef	Bike safety equipment – light reflectors	"1", if bicyclist uses light reflectors or else "0"	Categorical
OET	Bike safety equipment – other electronic tools	"1", if bicyclist uses other electronic tools or else "0"	Categorical
YIDS	"Yes, I do support AV even if the detection of bicyclists and pedestrians requires more improvement"	"1", if bicyclist supports AV even if AV requires improvement or else "0"	Categorical
PRICE	Price of the bike-mountable DSRC device	\$1000, \$750, \$500, \$250	Continuous

Separate logistic analyses are conducted using independent variables related to socio-demographic data, bike trip destination information, speed limit on the bike route travelled, level of safety experienced while cycling, and traffic and roadway characteristics. A table describing all of the considered independent variables is displayed in Appendix C. The results for these other independent variables indicate that all variables except the "price" variable remain insignificant. The physical environment appears to have no impact on whether a bicyclist needs a DSRC safety device or not. The infrastructure, socio-demographics, and roadway and traffic characteristics variables may appear insignificant because the survey responses represent a particular sub-population of bicycling enthusiasts and the sample appears fairly homogeneous.

Results

The summary of the binary logit model is shown in Table 2. The final model only includes significant variables that meets a 95% level of confidence. If the sign of a coefficient is positive, then an increase in the corresponding explanatory variable increases interest in the DSRC device and if the sign of the coefficient is negative then an increase in the corresponding explanatory variable results in a decrease in the interest for the DSRC device.

TABLE 2. Final Logistic Model

Name	Coefficient	Odds Ratio
3_5D	2.674	14.5012
1_2D	2.646	14.0963
FRL	-2.019	0.1328
HCC	-1.161	0.3133
LRef	1.064	2.8983
OET	0.766	2.1501
YIDS	1.825	6.2041
PRICE	-0.002717	0.9973

The author uses a Hosmer-Lemeshow test to assess the model's goodness-of-fit. This test compares the predicted distribution to the observed distribution using a Chi-square test; please see section 5.2.2 “The Hosmer-Lemeshow Tests” (*20*) for a more detailed explanation. In this case, failing to reject the null hypothesis indicates the model does not produce unsatisfactory results. The author performs the Hosmer-Lemeshow test at a 95% level of confidence and obtain a P-value of 0.819; this result indicates that the model fit appears acceptable. Since the overall model seems appropriate, the author discusses the importance of the significant independent variables and their influence on the dependent variable.

From the question category of bike usage frequency, “3-5 days/week” and “1-2 days/week” represent the significant independent variables in the model. The model building process indicates that daily users do not appear significantly different from rare users. Although daily riders represent a great target market, they may actually be less interested in the device because they have a high confidence in their cycling skills and ability to avoid a crash. The positive coefficient for “3-5Days/week” and “1-2Days/week” variables indicate that regular but not daily bicycle riders, use a bike enough to encourage interest and consider DSRC device adoption. In fact, this regular usage provides a strong indicator of support with high odds ratios of 14.5012 and 14.0963 for the “3_5D” and “1_2D” variables, respectively.

The model includes additional independent variables from the question category of safety equipment used by bicyclists. The independent variables “helmet” and “nothing” do not appear to be significant. Each use of safety equipment may be regarded as providing an additional layer of safety for the bicyclist. The final model includes numerous safety equipment variables (front or rear light, high contrast clothes, light reflectors and others (electronic tools)). The negative coefficients for front or rear light and high contrast clothes indicate that bicyclists who invest in one of options appear less likely to show interest in the additional layer of safety provided by a bike-mountable DSRC device. If a bicyclist uses any of these safety equipment then these two variables create a decrease in the demand for a bike-mountable DSRC device. However, the coefficient of light reflectors remains positive because light reflectors are available by default on all new bicycles, a bicyclist may not be convinced about the level of safety provided with just light reflectors. Hence, the independent variable "LRef" has a higher odds ratio than the other three independent variables for safety equipment. Another independent variable with a positive coefficient is the use of other electronic tools. This indicates that previous adoption of a cyclo-computer strengthens a respondent's interest in the DSRC device. The high odds ratio for other electronic tools corroborates with the initial hypothesis that cyclo-computer users may be pre-disposed to show interest in a bike-mountable DSRC device. These variables representing safety equipment suggest that the type of safety equipment currently selected by a bicyclist may highly influence their demand/interest for a bike-mountable DSRC device.

The variable considers a bicyclist's opinion of AVs. The positive coefficient for the variable "yes, I do support AVs even if the detection of bicyclists and pedestrians requires more improvement" suggests that bicyclists may be willing to cope until a fully functional and fully efficient AI for AVs is built. They support using AVs regardless of the skepticism revolving around the current AV technology. The odds ratio of 6.2041 infers that bicyclists want to keep themselves safe by communicating continuously with AVs irrespective of whether the AI residing inside the AVs can fully respond to bicyclists or not. Clearly, personal perceptions and attitudes play an important role in DSRC device interest and willingness to purchase.

As expected, the model indicates that an increase in price decreases interest in the DSRC device. The odds ratio of 0.9973 for "price" indicates that the use of high contrast clothes or bicycle lights decrease interest more than a $250 increase in price. The author recommends considering current bike use, equipment investment, type of safety equipment in use, opinion about the usage of AVs and price of the bike-mountable DSRC device when predicting the demand for a DSRC device in the future.

CONCLUSION

The survey and model results show that the need for improvement in AVs to safely operate on streets does not hinder bicyclists from opting to use a bike-mountable DSRC device that acts both as a V2X communication device as well as a bike accessory. The demand for developing a bike-mountable DSRC device shows that the public has interest in increased safety regardless of their perception towards AVs. Deploying a bike-mountable DSRC device for bicyclists just for detection in V2X communications may seem to be a burden to the pockets of bicyclists, but this research proves that deploying DSRC devices as a bike accessory or safety gadget for bicyclists, may impact the willingness to opt for DSRC device amongst the bicyclists. Demographics and the physical environment appear to bear no impact on the interest of purchasing a bike-mountable DSRC device but rather the frequency of bike use, safety equipment investments, type of safety equipment and bike-mountable DSRC device price play a major role in determining demand for a bike-mountable DSRC device. Though 70% of the bicyclists mentioned that they support AVs only if AVs detect bicyclists in all conditions, the percentage of bicyclists not interested in a bike-mountable DSRC device was only 47%, when the price of the device dropped to $250. Here, the low price of the device may have allured the respondents to show interest for the device but simultaneously, one may also infer that the respondents give importance to safety, irrespective of their impressions of AVs.

Detection of bicyclists using DSRC communication appears to be easier for AVs than relying only on sensor based detection techniques. The parameters (e.g. latitude, longitude, altitude, speed, heading angle, etc.) emitted as BSM by bicyclists can help AVs predict the path and behavior of bicyclists in real-time, which can help AVs avoid bicyclists. Simultaneously, the DSRC data from bicyclists can be utilized in framing operation requirements for AVs. The feasibility of a bike-mountable DSRC device is reliant on factors, other than those discussed in this research. These factors include:

a) Government's recognition and approval of using DSRC as a strategy to address safety issues of bicyclists.

b) Research work highlighting that B2X communications pose no major technical challenges that might affect the performance of V2X communications.

c) Public's acceptance.

d) Technical development of a bike-mountable DSRC device at an affordable price.

Bringing bicyclists into DSRC communications also unlocks the doorway to many mode-driven safety applications. A few of the possible safety applications for bicyclists are discussed in Appendix D.

To explore the demand for a B2X communication device more, the analysis can be made using a larger sample size and new target markets. This research did not involve survey respondents with age less than 18 years. Including children in a future study may open another market for DSRC adoption because cycling skills of children may not suffice to avoid the AVs on roads and hence parents may be interested in a bike-mountable DSRC device.

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APPENDIX - A

ADDITIONAL BACKGROUND AND DESCRIPTION OF CV SYSTEMS

History of ITS

When the United States planned and built the interstate highway system, it provided citizens with a high level of mobility and efficient movement of goods. Until the 1980s, the highway transportation was largely focused upon building roads and providing higher accessibility. After building widespread highway infrastructure, issues, such as highway fatalities and injuries due to crashes, urban area traffic congestion, impressions of fuel and energy consumption, and air quality, began to surface. In the mid-1980s, this shifted the focus from the belief of increasing infrastructure to tackle the issues, towards finding the solutions within the built system. This shift made transportation professionals from Federal agencies, academia, state transportation agencies and the private sector debate over the future of transportation in the post-interstate period. It also necessitated a new perspective of transportation that uses the current infrastructure to address the issues of safety, congestion, energy and environment. This debate culminated in developing the Intelligent Vehicle Highway Systems (IVHS) concept in Dallas, Texas in 1990. IVHS was later renamed to Intelligent Transportation Systems (ITS). The new perception of transportation that originated was that efficiency in transportation can be achieved with the amalgamation of current infrastructure and advanced technology. It was envisioned that the key to increase the efficiency of the operational capacity of the system and transportation network lies in the development of new computing tools, advanced mathematical methods, sensors and information systems (*10*).

The major breakthrough occurred when the potential safety application hosted by vehicle to vehicle communication was foreseen by DOT and the Crash Avoidance Metrics Partnership

(CAMP). V2V research was first initiated in December 2006. A report by USDOT stated, "DSRC, as a Wi-Fi-based technology, provides 360 degrees of coverage, whereas vehicle-based sensors can be more limited in terms of direction and distance at which they are able to detect a potential conflict" (*10*).

In 1997, following the requirement of wireless communication between vehicles, the Intelligent Transportation Society of America (ITSA) appealed to the U.S. Federal Communications Commission (FCC) for the apportionment of 75MHz of licensed spectrum around the 5.9 GHz band for applications of Intelligent Transportation Systems (ITS). In 1999, the FCC approved the allocation of the band by stating, "By this action, we allocate 75 megahertz of spectrum at 5.850 - 5.925 GHz to the mobile service for use by Dedicated Short Range Communications (DSRC) systems operating in the Intelligent Transportation System (ITS) radio service. ITS services are expected to improve traveler safety, decrease traffic congestion, facilitate the reduction of air pollution, and help to conserve vital fossil fuels." The main goal behind allocating this spectrum for DSRC communications and making this a DSRC standard is to open the door for vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) communications that assist the safety applications meant for both vehicles and the public. Apart from the safety, V2V and V2I communications are also very effective in enhancing traffic flow. The term "dedicated" also refers to the allocation of 5.850-5.925 GHz spectrum and whereas "short-range" means that the communication happens over hundreds of meters, which is shorter than cellular and worldwide interoperability for microwave access (WiMax) communications. As stated by USDOT, "dedicated short-range communications (DSRC) are two-way, wireless communications permitting secure and fast messaging needed for safety applications, where 'short-range' is approximately 300 meters depending on the surrounding environment. These communications occur in a 75 MHz band around the 5.9 GHz spectrum, which has been allocated by the FCC for use by Intelligent Transportations Systems (ITS) vehicle safety and mobility applications. This band affords a relatively clean operating environment with very few preexisting users, allowing for a relatively unimpeded and interference-free communication zone" (*10, 21*).

The safety applications driven by DSRC are very much dependent on data that is exchanged frequently between the vehicles, and vehicles and roadside infrastructure. The data that is broadcast periodically is called the basic safety message (BSM). A BSM is a message set that contains information such as longitude, latitude, altitude, speed, heading direction, brake status, and vehicle size, that is utilized for safety applications. The BSM transmitter in the DSRC device collects GPS data as well as the data from on-board sensors of the vehicle and transmits the messages to the surrounding vehicles. The BSM is broadcasted every $1/10^{th}$ of a second for few hundred meters. The neighboring vehicles equipped with DSRC receive the transmitted BSM. The vehicle that receives this information uses this data and computes the trajectory of neighboring vehicles. After being aware of the nearby vehicles trajectories, it compares its trajectory with nearby vehicles trajectory and ascertains if any of the neighboring vehicles poses a threat. This is a typical example of how V2V communications occur. The V2I communications also occur in the same way but they differ in the type of messages exchanged. The V2I communications occur specifically between vehicles and roadside equipment (RSE). The RSE are the DSRC devices that are fixed or placed on the infrastructure. The RSE were developed to address the issue of transmission of BSM in case of obstacles such as buildings and other structures that are prohibiting the waves of DSRC. The RSE acts as a mediator as well as transmits other types of messages to the vehicles. The other types of messages may include information such as signal phasing and timing (SPaT), geometry of an approaching intersection, the status of the signal at intersection, and the existence of a hazard (e.g. lane closed due to construction, emergency vehicle, and weather condition). When the vehicle receives the messages from RSE and it determines the possibility of any hazards such as violation of a red light, then the on-board system warns the driver to be aware of the hazard. The warning is conveyed to the driver either in the visual form (e.g. on dashboard screen), in an audio form (e.g. inbuilt infotainment voice assistant), tactually (e.g. vibrating steering wheel) or a combination of these. When the driver calls to take an action, then the on-board system helps in controlling the vehicle. In case the driver fails to take an action to avoid the hazard, then the on-board system automatically applies brakes or makes a graceful decision to avoid the damages to be caused by the hazard. The communications between DSRC devices must occur as per the standards set by the IEEE and USDOT whereas the on-board vehicle environment and hazard warning system in a vehicle is deployed by the automobile manufacturer (*10*, *21*).

The 5.9 GHz DSRC spectrum (refers to 5.850-5.925 GHz band) allocated in U.S. by FCC has got 75 MHz band. It is divided into seven 10MHz channels with initial 5 MHz guard band dedicated for protection from adjacent frequencies. Channels of 10 MHz have been named by even numbers between 172 and 184. In some cases, pair of 10 MHz (174/176 and 180/182) can be combined to form one 20 MHz channel, designated by FCC as 175 and 181 respectively, for operating safety or non-safety applications. The channel 178 that lies in the middle of the spectrum (5.885-5.895 GHz) has been designated by FCC as control channel (CCH) and is used only for safety communications. The FCC has assigned channel 172 (5.855-5.865 GHz) exclusively only for V2V safety communications for crash avoidance (accident avoidance and mitigation), and safety of life and property applications. This channel is also known as high availability, low latency (HALL). CH 172 hosts three types of messages namely BSM (V2V), MAP message (V2I), SPaT (V2I). The channel 184 (5.915-5.925 GHz) is designated by FCC exclusively for high-power long-range (HPLR) communications that are used for public safety applications involving safety of life and property including road intersection collision mitigation. Mainly road authorities and public agencies use this channel. The channels other than 178 are designated as service channels (SCH) that can be used for safety as well as non-safety applications (*10, 21*).

Why DSRC?

DSRC was developed mainly to facilitate vehicle safety applications because its potential lies in the fact that it significantly reduces the number of most of the deadly type of crashes through real-time adversaries alerting drivers to imminent hazards (such as veering close to the edge of the road, vehicles suddenly stopping ahead, collision paths during merging, the presence of nearby communications devices and vehicles, sharp curves, or slippery patches of roadway ahead). Though the DSRC device has crucial vehicle safety applications, its functionality and operability features make the vehicle safety features possible. DSRC is the only short-range wireless communication device that provides fast network acquisition, low latency, high reliability when required, priority for safety applications, interoperability, security and privacy (*10, 21, 22*).

Safety Applications of V2V

The potential applications enabled by V2V are the applications that are not currently available to drivers and those which could not be achieved without V2V communications. The following is a list of important applications.

1. Intersection Movement Assist (IMA):

   The driver is warned when it is unsafe to enter the intersection because of the higher possibility of potential collision with one or more vehicles.

2. Forward Collision Warning (FCW):

   The driver is warned about the risk of having a rear end collision with another vehicle which is ahead in the traffic in the same lane and direction of travel.

3. Blind Spot Warning (BSW) and Lane Changing Warning:

   The driver is notified when another vehicle in an adjacent lane is spotted in "blind spot" zone. IF the driver attempts to change the lane during this scenario then LCW warns the driver that a vehicle is present or approaching the "blind spot" zone.

4. Emergency Electronic Brake Light (EEBL):

   The driver is warned to be prepared to take action when a V2V equipped vehicle travelling in the same direction but not in the driver's line of sight decelerates quickly. V2V would allow the driver to "see through" vehicles or poor weather conditions and know if traffic ahead may be coming to an abrupt stop.

5. Do-Not-Pass Warning (DNPW):

   The driver is warned when it is not safe to pass a slower-moving vehicle when vehicles are approaching from the opposite direction.

6. Cooperative Adaptive Cruise Control (CACC):

   The preceding vehicle's acceleration is obtained from the DSRC technology and the host vehicle uses this data for longitudinal control through throttle and brake activations. This application is very useful for platooning and mobility purposes (*10, 21, 22*).

Safety applications of V2I

The wireless technology used in V2V communications is more like a path to support wide-ranging set of safety and mobility applications than to just use it as a communication tool. V2V combined with compatible roadway infrastructure functions as the gateway for the expansive intelligent transportation system program. V2I communications mainly exchange messages of highway infrastructure, traffic signal phasing and timing, approaching intersection's operation and weather status, critical safety messages and other types of messages such as traveler information message that benefit environmental and mobility applications. V2I also plays a key role in developing applications for commercial freight operators and transit agencies. The potential applications enabled by V2I are the applications that are not currently being addressed by V2V or addressed inefficiently and those which could not be achieved without V2V communications. The following is a list of important applications.

1. Red Light Violation Warning
2. Curve Speed Warning
3. Stop Sign Gap Assist
4. Reduced Speed Zone Warning
5. Spot Weather Information Warning
6. Stop Sign Violation Warning
7. Railroad Crossing Violation Warning
8. Oversize Vehicle Warning
9. Signal Phasing and Timing (SPaT)
    a. Red Light Running
    b. Left Turn Assist
    c. Right Turn Assist
    d. Pedestrian Signal Assist
    e. Emergency Vehicle Preempt

f. Transit Signal Priority

g. Freight Signal Priority

Further development of mode-specific applications is being done in collaborations with FHWA, FTA, FMCSA and the Federal Railroad Administration (*10, 21*, *22*).

The V2I safety research program aims to create national interoperability to support infrastructure and vehicle deployments and facilitate cost-effective infrastructure deployment. Certain messages types or data stored by the vehicles will benefit mobility, weather, and environment applications. The NHTSA has a major role in influencing the vehicle manufacturers to provide storage and cellular capabilities so that the trip data can be used for mobility, weather and environment applications. For example, when DOTs deploy RSE units initially and vehicles enabled with V2V arrive in the coverage area of RSE then vehicles can feed the travel information data to RSE or download data from RSE that facilitates safety and non-safety messages that informs the drivers about the traffic, road and weather conditions of the surrounding environment. If the cellular broadcast is enabled, then vehicles will be able to regularly transmit the data about their status and operation which then helps the safety applications. All vehicles approaching an intersection should be able to receive V2I messages (*10*, *21*, *22*).

APPENDIX - B

SURVEY SHEET

Safety aspects of Bicyclists within Autonomous/Self-Driving Vehicle Environment

1) Do you _____ a bicycle?

a) Own b) Rent

2) Gender

a) Male b) Female

3) What is your education status?

a) High school b) College c) Bachelor's d) Master's e) Others

4) Your age:

a)18-25 d)26-35 e)36-50 f) 50+

5) How often do you ride the bicycle?

a) Daily b)3-5 days/week c) 1-2 days/week

d) rarely I use bicycle (once or twice in a month)

6) You frequently travel on bicycle to

a) School/College b) Work c) Recreational/Park/Exercise

d) Other places (Grocery Store, friend's home, religious etc.)

7) What precautionary equipment do you use while travelling on bicycle? (Select all that apply)

a) Helmet

b) Front/Rear light

c) High contrast clothes

d) Light reflectors

e) Others (Electronic tools e.g. GPS navigator etc.)

f) Nothing

8) Your frequently travelled bike route has speed limit of

b) <=20mph (e.g. School Zone, High density Residential Areas)

b) 20-35mph (e.g. low density Residential Areas, local roads)

c) 35-45mph (e.g. Arterials)

d) 45-60mph (e.g. High speed arterials and minor highways)

e) >=60mph (e.g. Freeways, Highways)

9) How safe do you feel while travelling on the route?

(Your response should be based on the route selected in Question **8**.)

a) Very Safe b) Safe but slightly afraid c) I frequently get afraid to ride

d) I do not feel safe at all

10) What elements of the road make you ***feel unsafe*** while riding on bicycle?

(based on previous response)

(Select all that apply)

a) High speed traffic involving cars & trucks

b) High volume of traffic involving cars & trucks

c) No bike lanes / narrow travel lanes

d) Insufficient light and poor visibility

e) Approaching intersections(with traffic signal) and intersection crossing

f) Right turn movement of motor vehicles / No traffic signal or Stop sign for motor vehicles at intersections

g) Two-way traffic

11) What elements would make you ***feel safe*** while riding on bicycle?

(Select all that apply)

a) Proper light and visibility

b) Bike lanes / wide travel lanes

c) Body gear (Helmet, High Contrast Clothes, etc.)

d) Less or no motorized traffic

e) Low speed limits for the motor vehicles

f) One-way traffic

g) Bike lanes travelling in the same direction as the motor vehicles travel lane

12) While navigating, many autonomous (or self-driving) vehicles (AV) receive sufficient information by communicating with other vehicles.

But bicyclists and pedestrians may need to be detected using sensors (on-board) of AV, which may be more subject to environmental conditions and software capability.

Do you support using autonomous vehicles on the streets?

a) Yes, I do support even if the detection of bicyclists and pedestrians requires more improvement

b) No

c) Yes, only if autonomous vehicles are fully capable of detecting bicyclists and pedestrians and avoid them under all circumstances

d) I am not sure / No opinion

13) There is a bike-mountable device that communicates with autonomous vehicles for bike detection and it can also be used as a navigation tool. Its other features may include synchronization of data with mobile through an app, trip recorder, parking locater, etc. (The size of the device is almost the same as most of the smart phones currently available and also it can be mounted on motorcycles)

Will you buy if the device costs **$1000**?

a) Yes   b) No

c) Maybe (In the near future if I require or Depends upon the other features of the device)

d) No opinion

Will you buy if the device costs **$750**?

a) Yes   b) No

c) Maybe (In the near future if I require or Depends upon the other features of the device)

d) No opinion

Will you buy if the device costs **$500**?

a) Yes   b) No

c) Maybe (In the near future if I require or Depends upon the other features of the device)

d) No opinion

Will you buy if the device costs **$250**?

a) Yes   b) No

c) Maybe (In the near future if I require or Depends upon the other features of the device)

d) No opinion

APPENDIX – C

TABLE DESCRIBING ALL THE INDEPENDENT VARIABLES OF SURVEY QUESTIONNAIRE

Question Category	Choices	Reference Variable	Variable Code Name
Gender	Male		Male
	Female	Female	Female
Education Status	High school		High school
	College		College
	Bachelor's		Bachelor's
	Master's		Master's
	Others	Others	Others
Age, in years	18-25	18-25	18-25
	26-35		26-35
	36-50		36-50
	50+		50+
Bike usage frequency	Daily		Daily
	3-5 days/week		3_5D
	1-2 days/week		1_2D
	Rare usage	Rare Usage	Rare_usage
Frequently travelled destination	School/College		School_College
	Work		Work
	Recreational/Park/Exercise		Recreational
	Other places	Other places	Other_places
Precautionary equipment used	Helmet	NA	Helmet
	Front/Rear Light	NA	FRL
	High contrast clothes	NA	HCC
	Light reflectors	NA	LRef
	Others (Electronic tools)	NA	OET
Frequently travelled bike route speed limit	<=20mph	NA	20mph
	20-35mph	NA	20_35mph
	35-45mph	NA	35_45mph
	45-60mph	NA	45_60mph
	>=60mph	NA	60mph
Level of safety according to bicyclist	Very Safe		VerySafe
	Safe but slightly afraid		Safebut
	Frequently get afraid to ride		Freq_afraid
	Do not feel safe at all	Do not feel safe at all	Not_safe
Elements of road that make bicyclist feel unsafe	High speed traffic involving cars and trucks	NA	High_speed
	High volume of traffic involving cars and trucks	NA	High_volume

	No bike lanes/narrow travel lanes	NA	No_bike_lanes
	Insufficient light and poor visibility	NA	Poor_light
	Approaching Intersections and intersection crossing	NA	Intersections
	Right turn movement/no traffic signal/no stop sign	NA	Right_turn
	Two-way traffic	NA	Two_way
Elements of road that make bicyclist feel unsafe	Proper light and visibility	NA	Proper_light
	Bike lanes/wide travel lanes	NA	Bike_lanes
	Body gear	NA	Body_gear
	Less or no motorized traffic	NA	Less_traffic
	Low speed limits for vehicles	NA	Low_speed
	One-way traffic	NA	One_way
	Bike lanes travelling in the same direction as vehicles travel lane	NA	Bikelanes_samedirection
Do you support usage of AV on streets?	Yes, I do support even if it requires improvement for detection of bicyclist		YIDS
	No	No	No
	Yes, only if AVs detect bicyclists all the time		Yes_OnlyIf
	I am not sure/no opinion		NotSure
Would you buy bike-mountable device if it costs: $1000 $750 $500 $250	Yes	NA	$1000 $750 $500 $250
	No	NA	DV: “Yes/Maybe = 1”,
	Maybe (Depends upon features)	NA	“No = 0”
	No Opinion	NA	

APPENDIX – D

POTENTIAL SAFETY APPLICATIONS FOR BICYCLISTS

The NHTSA reported that in 2013, 57% of pedalcyclist fatalities occurred at non-intersections (*6*). One of the possible reasons for this could be the conflict of paths between a driver making a right turn and crossing a bicyclist's path, who was cycling in the same direction. Many crashes between a driver and bicyclist likely occur due to driver inattention or incomplete surveillance of the surrounding traffic. In such a scenario, BSM transmitted from a bicyclist's VAD is received by the AV and after calculating the trajectory of both, if any conflict between the paths exists, the AV may alert the driver of any potential hazards related to path conflicts. A bike-mountable DSRC device may also be able to enhance safety where no bike lanes exist and an AV overtakes a bicyclist. If the AVs AI has a minimum separation of 4 feet from bicyclists, then the AVs can perform the required calculations and will overtake the bicyclists only when the operating requirements are satisfied. Another possible safety application that can be enabled is during the right turn on red at intersections. At unprotected right turn signals, vehicles can make cautious right turns which might conflict with pedestrian or cyclists crossing. During such situations, when bike-mountable VAD transmits BSM to surrounding V2V and V2I communications devices, right turning vehicles at intersections can be alerted based on the BSM data and confirm that bicyclists are present at the intersection and are about to cross the intersection. At some bike dedicated intersections, a high level of bicyclist activity can increase the bicyclist priority level during the signal phasing and timing. This can possibly eliminate the use of loop detectors for bicyclist detections at intersections.

Another possible bike-oriented safety application that can be enabled is safeguarding child bicyclists against AVs. The reason for involving the parents of children with age less than 18 years, in this kind of research is that the ability of bike-mountable DSRC device to communicate with AVs, could also be used as a safeguard for children against AVs. Children cycling on roads can be exposed to AVs and during any potential hazardous situation, cycling skills of children may not suffice to avoid the potential hazard. Hence, parents might be interested in using the bike-mountable DSRC device as a safety tool for children under 18 years of age. Hence, an array of bike-based safety and non-safety applications can be enabled if bicyclists are also in the DSRC communication link along with vehicles.