


The Economic Costs and Benefits of a Federal Mandate that All Light Vehicles Employ 5.9 GHz DSRC Technology


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May 2, 2016



This report was prepared for the National Cable & Telecommunications Association, with support from Comcast. All results and any errors are the responsibility of the authors and do not represent the opinion of The Brattle Group, Inc. or its clients.

Acknowledgement: We acknowledge the valuable contributions of many individuals to this report and to the underlying analysis, including members of The Brattle Group for peer review.

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Executive Summary

On August 20, 2014, the National Highway Traffic Safety Administration (“NHTSA”) announced its proposal to mandate a vehicle-to-vehicle (“V2V”) communication standard in the 5.9 GHz band known as dedicated short range communications (“DSRC”). In the report accompanying the proposal (“V2V Technology Report”), the NHTSA presented preliminary estimates of the direct monetary costs of a potential V2V DSRC mandate and of the benefits in terms of reduced crash rates, fatality rates and crash severity under three different implementation scenarios. However, while highlighting the economic practicability and the potential safety benefits of a mandate, the NHTSA’s analysis has several limitations and ultimately does not constitute a suitable analytical framework to evaluate the full set of benefits and costs of a mandate. Most importantly, the NHTSA’s analysis:

1. Only measures the incremental costs and benefits of the technology relative to the current state of vehicle-safety technologies, and not relative to an appropriate baseline that includes other expected safety improvements.
2. Does not consider the opportunity costs of the spectrum or whether alternative spectrum sharing scenarios could meet the technology’s objectives and requirements and promote its efficient use.
3. Does not consider the plausible externalities—positive or negative—that a mandate on V2V would have on investment in, and development of, substitute and complementary vehicle-safety technologies.
4. Does not attempt to monetize the welfare benefits of a mandate.

In addition to these major limitations, the NHTSA’s analysis suffers from many potential inaccuracies. The overall effect of these limitations and inaccuracies is to paint an overly optimistic picture of the current DSRC proposal and to fail to maximize total benefits by ignoring the opportunity cost of not sharing spectrum in the 5.9 GHz band with unlicensed uses when spectrum sharing has the potential to maximize consumer welfare while still permitting the NHTSA to accomplish V2V safety of life objectives.

In this paper, we review and adjust the NHTSA’s analysis, and extend it to analyze the welfare effect of a V2V DSRC mandate under alternative policy configurations, relative to an alternative scenario in which V2V is not mandated. Building on the NHTSA’s analysis, we develop a preliminary cost benefit analysis (“CBA”) that accounts for the likely trends in safety

technologies, allows for some possibility of failure and miscommunication among DSRC devices, and monetizes the safety benefits in accordance with the Office of Management and Budget (“OMB”) guidelines. To highlight the opportunity costs associated with spectrum use, we compare a mandate assigning the full 75 MHz of spectrum for exclusive DSRC use to an alternative scenario that conservatively provides for exclusive DSRC use of the upper 30 MHz of the 5.9 GHz band. Under the plan, originally proposed by Qualcomm, unlicensed Wi-Fi would only share the lower 45 MHz of the 5.9 GHz band. The proposal would capture the full safety benefits of V2V technology and at the same time promote efficient use of the scarce spectrum resource.

We estimate the welfare effects of a V2V DSRC mandate as of 2015, both under the NHTSA original assumptions and under appropriately revised assumptions, and account for the opportunity cost of the scarce spectrum resource. We conclude that:

1. NHTSA’s inappropriate application of assumptions and baseline overstates the net benefit of a V2V DSRC mandate by hundreds of billions of dollars. Once the NHTSA’s assumptions are properly adjusted, the net benefits of a V2V DSRC mandate are dramatically reduced and, under some parameter assumptions, become negative.
2. The net benefits of a V2V DSRC mandate without spectrum sharing range between a net loss of \$140 billion and a benefit of \$442 billion, depending on the parameter assumptions. Conversely, the net benefits of a mandate allowing for shared use of the lower portion of the 5.9 GHz band would always produce large, positive benefits ranging between \$191 and \$744 billion.
3. Shared use of the lower portion of the 5.9 GHz band would both achieve the full safety benefits of V2V communications and maximize the value of the spectrum regardless of the parameter assumptions used. Shared use would produce a surplus ranging between \$166 and \$603 billion.

I. Introduction

On August 20, 2014, the NHTSA published an Advance Notice of Proposed Rulemaking (“ANPRM”)¹ in which it announced a proposal to mandate “vehicle-to-vehicle (V2V) communication capability for light vehicles [...] and to create minimum performance requirements for V2V devices and messages.”² Specifically, NHTSA proposed to mandate a type of V2V communications called DSRC.³ The proposal was accompanied by an extensive report on the readiness of V2V technology (“V2V Technology Report”)⁴ and invited commenters to submit—no later than October 20, 2014—their research, comments, additional information and data to inform the agency in the development of an effective proposal.

V2V is a technology “designed to transmit basic safety information between vehicles to facilitate warnings to drivers concerning impending crashes”⁵ through DSRC devices using wireless communication channels in the 5850-5925 MHz band (the “5.9 GHz” band, also known as the U-NII 4 band)⁶ that the Federal Communications Commission (“FCC”) made available for automotive use in 1999, on a shared basis with existing incumbents.⁷ Although none of the driver assistance applications that exist today rely on DSRC or the 5.9 GHz spectrum and other non-DSRC warning and crash-avoidance applications are in development, the NHTSA argues that DSRC “will either be the sole enabler of some safety applications or present a possible

¹ Department of Transportation, NHTSA, 49 CFR Part 571, Federal Motor Vehicle Safety Standards: Vehicle-to-Vehicle (V2V) Communications. Hereinafter, “ANPRM.”

² ANPRM at 49270.

³ NHTSA’s ANPRM proposes a “technology mandate” rather than an “outcome-based” rule leaving more flexibility to car manufacturers. The NHTSA believes that V2V capability would not develop absent a technology mandate since early adopters have no immediate safety benefits from the technology. See ANPRM at 49270.

⁴ NHTSA, “Vehicle-to-Vehicle Communications: Readiness of V2V Technology for Application,” August 2014. Hereinafter, “V2V Technology Report.”

⁵ V2V Technology Report, p. xiii.

⁶ The 5.85-5.925 GHz band is also referred to as U-NII 4. FCC 03-324, Report and Order, In the Matter of ET Docket No. 98-95 and RM-9096, adopted December 17, 2003 and Released February 10, 2004, p. 6.

⁷ V2V Technology Report, p. 63. Also, FCC 99-305, Report and Order, In the Matter of ET Docket No. 98-95 and RM-9096, adopted October 21, 1999 and Released October 22, 1999 (hereinafter, “Report and Order (1999)”).

enhancement to on-board systems.”⁸ In particular, the agency states that “DSRC is the only technology that can enable Intersection Movement Assist, Left Turn Assist, and Electronic Emergency Brake Light” functions.⁹ NHTSA’s ANPRM, however, does not explicitly propose to mandate these particular warnings, but only states that it would create minimum performance requirements for V2V devices and messages.¹⁰

DSRC relies on radio spectrum. However, sixteen years after the FCC made 75 MHz of spectrum available to intelligent transportation systems (“ITS”),¹¹ laying the groundwork for the current DSRC proposal, the 5.9 GHz band remains virtually unused for ITS purposes.¹² As demand for finite spectrum has reached unprecedented levels and is expected to continue to grow, the President and the Office of Management and Budget (“OMB”) have directed federal agencies to promote efficient use and sharing of the spectrum and to conduct cost-benefit analyses to evaluate the use of spectrum resources.¹³ In addition, in 2013 the FCC opened a proceeding to establish rules that would allow sharing of the 5.9 GHz band between DSRC and unlicensed Wi-Fi technologies.¹⁴

⁸ More generally, the agency claims that V2V DSRC technology has advantages over vehicle-resident sensor technologies both in terms of latency and range (V2V Technology Report, pp. xiv, 25 and 56). Results from extensive field trials in real world situations, however, evidenced how the reliable communication range—defined as the maximum distance with a communication error at or below 10 percent—might be well below NHTSA’s stated goal of 300 meters. In fact when testing a 400 byte basic safety message (“BSM”) transmitted at 6 Mbps the trials indicated a maximum reliable range of 51 meters for conventional DSRC. See Paul Alexander, David Haley, and Alex Grant, “Cooperative Intelligent Transportation Systems: 5.9-GHz Field Trials,” Proceedings of the IEEE, 2011, Figure 12, p. 1226. Note that the BSMs are likely to be transmitted at 6 Mbps with an average size of 375 bytes (V2V Technology Report, p. 96).

⁹ V2V Technology Report, p. 56.

¹⁰ See ANPRM at 49270. It is worth noting, however, that measuring the safety benefits of the technology, the NHTSA assumes that V2V devices are equipped with the Intersection Movement Assist (“IMA”) and Left Turn Assist (“LTA”) applications. It is not clear, however, that auto manufacturers will universally enable them absent an explicit mandate.

¹¹ V2V Technology Report, p. 87. See also Report and Order (1999).

¹² See, for example, Spector, Mike. “Will a Scramble for Airwaves Dent Talking Cars?,” May 18, 2015, available at <http://www.wsj.com/articles/will-a-scramble-for-airwaves-dent-talking-cars-1431984106> (accessed November 30, 2015).

¹³ Comments from Rick Chessen at the National Cable & Telecommunications Association, “Re: Federal Motor Vehicle Safety Standards: Vehicle-to-Vehicle (V2V) Communications, Docket No. NHTSA-2014-0022,” October 20, 2014, p. 2.

¹⁴ 78 Fed. Reg. 21320, at 21321 (Apr. 10, 2013).

Acknowledging the current FCC proceeding, NHTSA’s ANPRM invited commenters to provide additional research and evidence in support of or against sharing of the spectrum in the 5.9 GHz band, and asked whether unlicensed Wi-Fi technologies would interfere with V2V communications. NHTSA also requested advice on “how might NHTSA evaluate opportunity cost associated with [...] forgone alternative uses of the spectrum.”¹⁵

In the accompanying V2V Technology Report, the NHTSA presented preliminary estimates of the direct monetary costs of a V2V mandate and of the benefits in terms of reduced crash rates, fatality rates and crash severity under three different implementation scenarios.¹⁶ However, while highlighting the economic practicability and the potential safety benefits of a mandate, the NHTSA’s analysis has several limitations, fails to consider alternative uses of the 5.9 GHz band, and ultimately does not constitute a suitable analytical framework to evaluate the full set of benefits and costs of a mandate. In particular, the NHTSA’s analysis:

1. Only measures the incremental costs and benefits of the technology relative to the current state of vehicle-safety technologies, and not relative to an appropriate baseline that includes other expected safety improvements.
2. Does not consider the opportunity costs of the spectrum or whether alternative spectrum sharing scenarios could meet the technology’s objectives and requirements and promote its more efficient use.
3. Does not consider the plausible externalities—positive or negative—that a mandate on V2V would have on investment in, and development of, substitute and complementary vehicle-safety technologies.
4. Does not attempt to monetize the welfare benefits of a mandate.

In addition to these major limitations, the NHTSA’s analysis suffers from many potential inaccuracies. The analysis uses overly simplistic assumptions in the calculation of benefits and ignores the costs necessary to keep V2V devices current. Furthermore, the analysis does not provide support for the chosen implementation scenarios, and does not present reasonable sensitivity analysis with respect to most inputs, including discount rates, equipment costs, fuel

¹⁵ ANPRM, Section II.18.

¹⁶ V2V Technology Report, Sections XI and XII.

economy, and simulation results. The overall effect of the limitations of the NHTSA's analysis is to paint an overly optimistic picture of its DSRC proposal and to fail to maximize total benefits by ignoring the opportunity cost of not sharing its spectrum with unlicensed uses.

In this paper, we review and adjust the NHTSA's analysis, and extend it to analyze the welfare effect of a V2V DSRC mandate from an economic perspective, highlighting the opportunity costs associated with spectrum use and the benefits arising from the mandate under alternative policy configurations, relative to an alternative scenario in which V2V is not mandated. Building on the NHTSA's analysis,¹⁷ we develop a CBA that accounts for the likely trends in safety technologies, allows for the possibility of failure and miscommunication among DSRC devices, and monetizes the safety benefits in accordance with the OMB guidelines. Such analysis is required to perform a more accurate assessment of the costs and benefits of a mandate that will be useful to policy makers and comply with NHTSA's cost-benefit obligations.¹⁸

Critically, and in contrast to what NHTSA has done, such a cost-benefit analysis should seek to find the policy alternative that maximizes benefits relative to costs. Presenting an analysis, as NHTSA has done, that simply shows that one of many policy alternatives appears to have some benefits is incomplete, at best. Rather, the analysis should support choosing the policy alternative that creates the greatest benefits in excess of costs.

In the remainder of the paper, we start by providing an overview of the NHTSA's analysis in Section II. We then discuss the necessary elements of cost-benefit analysis as a decision procedure for regulatory action in Section III, and highlight the limitations of the NHTSA's analysis in Section IV. In Section V, we provide a measure of the opportunity cost of spectrum use in the 5.9 GHz band and show that efficient sharing of the spectrum would increase overall utility and public benefit. In Section VI, we extend and adjust the NHTSA's analysis to measure the net welfare effect of a mandate under both exclusive DSRC use and efficient sharing of the 5.9 GHz band.

¹⁷ Our economic analysis relies on NHTSA's estimates of the effectiveness of the IMA and LTA safety applications as critical inputs. While we acknowledge that such estimates are based on preliminary laboratory simulations, review of the NHTSA's simulations from a technical perspective goes beyond the scope of the current analysis.

¹⁸ See Executive Order 12866, "Regulatory Planning and Review," September 30, 1993, hereinafter, "Executive Order 12866," and OMB, "Circular A-4, Subject: Regulatory Analysis," September 17, 2003, hereinafter, "OMB Circular A-4." The NHTSA obligation to perform a cost-benefit analysis is detailed in Section III below.

The paper also contains two appendices. In Appendix A, we measure how the welfare effect of a mandate changes using alternative high and low values for a statistical life.¹⁹ As a key component of our broader analysis of the opportunity cost of spectrum use in the 5.9 GHz band, in Appendix B, we analyze the likelihood of congestion in residential Wi-Fi use with and without sharing of the band. Throughout the report, we interchangeably use 5.9 GHz and U-NII 4 to refer to the 5850-5925 MHz band.

II. Overview of the NHTSA's Analysis of Costs and Benefits of a V2V Mandate

The NHTSA estimates costs and benefits of mandating V2V DSRC technology under three different implementation scenarios.²⁰ The analysis focuses on the benefits associated with the Intersection Movement Assist (“IMA”) and Left Turn Assist (“LTA”)²¹ applications—which the agency believes will be exclusively enabled by V2V technology.²² The three different implementation scenarios use 2020 as the base year for implementation and differ in the adoption rate of V2V devices on both new and used vehicles.

¹⁹ As discussed in Section IV.D below, the DOT requires that the benefit of preventing a fatality should be “measured by what is conventionally called the Value of a Statistical Life (VSL) [...]” The DOT further requires sensitivity analysis using recommended alternative high and low values. US Department of Transportation, Memorandum To: Secretarial Officers Modal Administrators, From: Polly Trottenberg and Robert Rivkin, Subject: Guidance on Treatment of the Economic Value of a Statistical Life (VSL) in U.S. Department of Transportation Analyses, February 28, 2013, p. 1. Hereinafter, “DOT VSL Memo.”

²⁰ Sections XI and XII of the NHTSA Report detail the underlying methodology employed by the agency to construct its preliminary estimates of the costs and benefits of the deployment of V2V technology. As we discuss throughout, the NHTSA does not attempt to construct a present value of the costs. Instead, the NHTSA includes two different discount rates that are only used to discount the fuel economy impact on passenger vehicles.

²¹ V2V Technology Report, p. 259. IMA “warns the driver of a vehicle when it is not safe to enter an intersection due to a high probability of colliding with one or more vehicles at intersections both where a signal is present (a “controlled” intersection) and those where only a stop or yield-sign is present (an “uncontrolled” intersection).” LTA “warns the driver of a vehicle, when they are entering an intersection, not to turn left in front of another vehicle traveling in the opposite direction.” V2V Technology Report, p. 27.

²² V2V Technology Report, pp. xiv, 25 and 56, and footnote 8 above. As stated in the report the agency also intends “to examine the benefits of other safety applications [...] when sufficient data are available to estimate their effectiveness.” V2V Technology Report, p. 260. The agency also acknowledges certain limitations of the system due to reliance on the GPS signal, urban canyons, tunnels, and heavy foliage. V2V Technology Report, pp. 26 and 105.

- Scenario 1 involves an aggressive implementation schedule including the installation of aftermarket devices on used cars. The adoption rate for new cars is assumed to rapidly increase from 35 percent in 2020 to 70 percent in 2021 to 100 percent for the following years. Installation of aftermarket devices on used vehicles is assumed to start in 2022 and apply to model years 2015 through 2021. The installation rate on applicable vehicles is assumed to be 5 percent in 2022 and 2023 and 10 percent in 2024 through 2026. Each car with the technology installed is further assumed to have the two safety applications enabled.
- Scenario 2 involves the same adoption schedule of the technology on new cars as Scenario 1, but does not include the installation of aftermarket devices on used cars. Scenario 2 also involves a slower adoption rate of the two safety applications. Specifically, not all devices on new cars come with the two applications enabled. Rather, the installation rate of the safety applications would start at 50 percent for model years 2020-2022, and phase up to 100 percent for model year 2027.
- Scenario 3 presents the least aggressive schedule with low adoption rates and no aftermarket installations on used cars. The adoption rate for new cars is assumed to be 5 percent in 2020, 15 percent in 2021, and 25 percent for the following years.²³ The installation rate of the safety applications is assumed at 100 percent.

A. COSTS

The NHTSA considers four categories of (direct) monetary costs arising from the implementation of V2V technology.

Vehicle Equipment Costs. The NHTSA estimates the vehicle equipment costs to consumers for both new and used vehicles under the three implementation scenarios using confidential information provided by two suppliers. V2V systems would be adopted at different rates across the three scenarios, and costs are assumed to decrease over time due to a learning curve that

²³ V2V Technology Report, pp. 230-231. Note that Scenario 3 does not constitute a mandate and results in much lower safety benefits. The scenario was possibly considered by the NHTSA to provide evidence that the benefits of V2V communication can only be achieved if a vast majority of vehicles adopts the technology. In fact, as the report states, “[t]he disparity in benefits demonstrates that in order to realize the full potential of V2V technology, achieving full implementation over time is critical.” V2V Technology Report, p. 259.

improves the efficiency of the production process as more units are manufactured.²⁴ While new vehicles would have V2V systems installed by the original manufacturer, used cars that adopted the technology would be required to install aftermarket devices.²⁵ The NHTSA does not provide any sensitivity analysis for vehicle equipment costs.

Fuel Economy Impact. The fuel economy impact is estimated as the expected incremental cost of fuel over a vehicle's lifetime due to the increased weight of the vehicle as a result of the installation of the V2V device. The impact is measured as a function of mileage, survival probability, price of gasoline, change in vehicle fuel economy due to the added weight, and discount rate.²⁶ The NHTSA estimates an increase in lifetime fuel costs for passenger cars ranging between \$9.51 and \$12.38 for model-year 2020 and between \$9.04 and \$11.76 for model-year 2025 depending on the discount rate.²⁷ Similarly, the NHTSA estimates the increase in costs for light trucks to range between \$11.90 to \$18.56 for model-year 2020 and between \$11.36 and \$17.70 for model-year 2025.²⁸ The NHTSA does not include any sensitivity analysis with respect to unit weight, fuel prices or vehicle fuel economy.²⁹

²⁴ The V2V Technology Report is not explicit about the learning curve used in the analysis. V2V Technology Report, p. 217.

²⁵ The NHTSA considers three types of aftermarket devices: "Retrofit" and "Self-contained"—which would both send and receive BSMs and provide warnings to drivers—and "Vehicle Awareness" devices (VAD)—which would only send out BSM, but would not receive communications from other vehicles or provide warnings to the driver. V2V Technology Report, p. 218. It is worth noting that it is hard to imagine why a vehicle owner would install a VAD that would mostly benefit other vehicles absent an explicit obligation. While potential considerations might be compatibility and price, the NHTSA provides no justification as to why and how it would mandate (or even facilitate) the installation of such devices on 5 to 10 percent of used model years 2015-2021 vehicles.

²⁶ The NHTSA used various sources to project these measures including the Information Administration Annual Energy Outlook 2013 early release for mileage and gasoline price projections, the National Vehicle Population Profile for survival probability, and confidential business information submissions by suppliers for change in vehicle fuel economy due to added weight. V2V Technology Report, pp. 233 – 235.

²⁷ V2V Technology Report, Table XI-16, p. 236. The decrease in cost from 2020 to 2025 model-year cars is due to the expected improvement in fuel economy assumed in the model.

²⁸ V2V Technology Report, Table XI-16, p. 236.

²⁹ Although fuel prices and vehicle fuel economy inevitably have significant uncertainty over the timeframe of this analysis, the relatively small estimated costs do not warrant additional sensitivity analysis.

System Communication Costs. Estimates of system communication costs are based on a study by Booz Allen Hamilton (“BAH”) commissioned by the Department of Transportation (“DOT”).³⁰ Three protocols were considered for security system communications: 1) Cellular, 2) Cellular, Wi-Fi and DSRC hybrid, and 3) DSRC which requires the installation of DSRC enabled roadside equipment (“RSE”)³¹ in order to facilitate communications between the on-board V2V units and the Securities Credentials Management System (“SCMS”).³² According to BAH, only DSRC would meet the necessary security requirements.³³ Furthermore, according to NHTSA, “[o]f the three scenarios considered, the DSRC with RSE ended up being the most economically viable as well as allowing for the most security.”³⁴

Security Credentials Management System Costs. According to the NHTSA, “the main function of the SCMS is to ensure that the communications from vehicles to other vehicles are authentic and can be trusted.”³⁵ The cost drivers for the SCMS are the hardware, software, facilities, and full

³⁰ Booz Allen Hamilton, “Communications Data Delivery System Analysis for Connect Vehicles: Revision and Update to Modeling of Promising Network Options,” May 29, 2013.

³¹ The NHTSA Report distinguishes between RSE, “communication equipment on the side of the road designed to receive and send communications between vehicles and the SCMS regarding certificates, CRL, etc.” and Infrastructure Equipment, “equipment on curves or at intersections designed to communicate information about the road or whether a light is green or red, etc. to a vehicle.” V2V Technology Report, p. 241.

³² Note that the system communication costs do not include the costs of services that “ensure that the communications from vehicles to other vehicles are authentic and can be trusted,” which are separately estimated as SCMS costs. Although it is unclear whether the NHTSA explicitly considered backhaul communication costs, these are likely included in the annual costs of the facilities of the “Pseudonym Certificate Authority” of the SCMS. See V2V Technology Report, pp. 252-256.

³³ See V2V Technology Report, p. 242.

³⁴ See V2V Technology Report, p. 251. Note that the key difference in costs between the DSRC on the one hand and cellular and Wi-Fi on the other is the cost of communicating data, which is assumed to be zero under the DSRC option. As a result, the total estimated communication costs of the DSRC protocol are much lower than the costs of the other two protocol designs. Costs for the DSRC protocol are limited to the costs of installation and maintenance of RSE. BAH used the National Household Transportation Survey to determine that 19,749 sites on the National Highways System, with a daily coverage of 74 percent would best serve the requirements of the system, achieving greater coverage than installation of 8,880 sites on interstate roads, and requiring much fewer sites than the 149,434 required on secondary roads. Costs of RSE include an initial installation cost of \$8,839, annual maintenance cost of \$7,482, and replacement costs of \$22,719 after a life cycle of 15 years. A linear, 15-years implementation is assumed. See V2V Technology Report, pp. 243, 248, 250.

³⁵ V2V Technology Report, p. 252.

time equivalent positions needed to support the certificates issuance.³⁶ The agency estimates the yearly costs to range from \$5 to \$36 million in 2020, and from \$23 to \$93 million in 2058, with an average annual cost of \$60 million between 2020 to 2058.³⁷ According to the NHTSA, these costs could be covered by a \$3.14 fee collected along with the purchase of each new vehicle or aftermarket equipment.³⁸

Combining the four components of the cost analysis, the NHTSA estimates that “the total costs to the consumer for each new vehicle will be approximately \$341 - \$350 [...] in 2020” and that “over time this amount will decrease to approximately \$209 - \$235 in 2058,”³⁹ due in large part to the learning curve in manufacturing. Across the three scenarios considered, the estimated total costs would range between \$0.3 and \$2.1 billion in 2020, \$1.1 and \$6.4 billion in 2022, and then gradually decrease to an annual range between \$1.1 and \$4.6 billion.⁴⁰

B. BENEFITS

As mentioned above, the NHTSA estimates the benefits of mandating V2V DSRC technology in terms of reduced crash rates, fatality rates and crash severity. Specifically, the agency estimates the technology’s “crash avoidance and crashworthiness effectiveness by comparing crash rates and injury probabilities of vehicles with and without V2V technology” under the three implementation scenarios considered.⁴¹ The benefit analysis focuses on estimating the benefits

³⁶ V2V Technology Report, p. 255.

³⁷ V2V Technology Report, p. 252.

³⁸ V2V Technology Report, p. 252. In order to estimate the cost per new vehicle sold, the NHTSA first estimates the yearly cost of the entire SCMS. This cost varies with the number of vehicles operating with V2V capabilities. In fact, as the number of V2V-equipped vehicles increases, the SCMS will need increased capacity to generate and issue security certificates for the additional vehicles. Averaging the cost of the system over a 40-year period resulted in an estimated annual cost of \$59 million (V2V Technology Report, p. 255). The estimated annual cost would be covered by a \$3.14 fee collected along with the purchase of each new vehicle or aftermarket device. Table XI-26 (V2V Technology Report, p. 255) summarizes the undiscounted total cost of the SCMS for selected years under the projected technology of Scenario 1.

³⁹ V2V Technology Report, p. 256.

⁴⁰ V2V Technology Report, p. 257. The report does not explain how these estimates were calculated. For example, the NHTSA reports the incremental cost of fuel at the individual vehicle level for cars and light trucks but does not report their relative incidence on total costs. Similarly, the agency does not indicate whether and how the fuel economy impact was applied to vehicles installing an aftermarket device.

⁴¹ V2V Technology Report, p. 259.

associated with the IMA and LTA applications—which the agency believes will be exclusively enabled by V2V technology.⁴² The agency properly excluded consideration of benefits associated with other possible safety applications that can be enabled by other, non-radio spectrum-dependent technologies.⁴³ The main inputs to the calculation of the benefit estimates are:⁴⁴

- Target Population. The target population of crashes considered includes fatalities, injuries, and property-damage-only crashes involving two or three passenger vehicles.⁴⁵
- Crash Avoidance and Crashworthiness Effectiveness. The NHTSA estimated the effectiveness of the IMA and LTA safety applications in avoiding or reducing the severity of crashes “by comparing crash rates and the injury probabilities of vehicles with and without V2V.”⁴⁶
- Communication Probability. The probability that two vehicles will have DSRC devices and can communicate with each other in a crash situation depends on the number of V2V original and aftermarket awareness devices deployed and the total number of vehicles in operation.

The total annual benefits from the two safety applications are derived by summing the benefit from crash avoidance and the benefit from crashworthiness. The benefit from crash avoidance is obtained by multiplying the target population of crashes by the effectiveness in crash avoidance times the communication probability. The benefit from crashworthiness is obtained by multiplying crashes that could not be avoided—equal to the target population times one minus the crash-avoidance effectiveness—by the crashworthiness effectiveness times the communication probability.

⁴² V2V Technology Report, pp. xiv, 25 and 56, and footnotes 8, 21 and 22 above.

⁴³ V2V Technology Report, pp. 26, 259.

⁴⁴ V2V Technology Report, pp. 259-260.

⁴⁵ The NHTSA used 2010 and 2011 CDS (“Crashworthiness Data System”) and FARS (“Fatality Analysis Report System”) data to determine that approximately 3.34 million crashes annually would be impacted by the V2V-based safety applications considered (V2V Technology report, p. 263). As we discuss below in more detail, using the 2010-2011 levels of crashes as the baseline target population through 2058 mischaracterizes and substantially overestimates the levels of crashes that would be expected without V2V technology deployed.

⁴⁶ V2V Technology Report, p. 259.

The agency estimates the maximum annual benefit from the two safety applications if passenger vehicles were all equipped with a V2V device and could always communicate with each other. Using those assumptions, the NHTSA estimates that IMA and LTA combined would prevent between 412,512 to 592,230 crashes, save between 777 and 1,083 lives, avoid between 191,202 and 270,011 non-fatal injuries, and eliminate between 511,118 and 728,173 incidents of damage to property each year.⁴⁷ The agency further estimates the undiscounted yearly benefits under the three different technology implementations. The maximum benefits would only be achieved under Scenarios 1 and 2, but achievement of the maximum benefits would occur later under Scenario 2 than under Scenario 1, due to a slower implementation pace. Under Scenario 3, the slowest implementation only reaching 25 percent penetration of the technology, the two safety applications would achieve approximately 6 percent of the maximum benefits.

The analysis does not attempt to compare costs to benefits. Costs are estimated in dollars, but are only estimated on a yearly basis, and are not discounted to their present value. Benefits are measured in terms of avoided crashes, fatalities, non-fatal injuries, and damages to property, but are not monetized. However, costs and benefits measured in different units are not sufficient to evaluate the welfare impact of a mandate. Ultimately, a policy maker must judge whether or not the benefits exceed the costs and, across different proposed policies, which policy benefits would exceed costs by the most. To do so, benefits and costs must be comparable. Consequently, we turn to the well-established principles of cost-benefit analysis that are designed to allow costs and benefits to be compared to each other.

III. Principles of Cost-Benefit Analysis

CBA is a primary tool for regulatory analysis that federal agencies are required to carry out, whenever possible, for all major rulemakings.⁴⁸ NHTSA's V2V Technology Report does not purport to be the full CBA required by law before the agency may impose new regulations. In anticipation of the execution of the full CBA, however, the V2V Technology Report contains much analysis that would be included in a CBA. With the goal of contributing to the development of a compliant CBA, this section describes, at a theoretical and analytical policy level, what a proper CBA does. Section VI will later reconcile the theoretical principles with

⁴⁷ V2V Technology Report, p. 286.

⁴⁸ See Executive Order 12866 and OMB Circular A-4.

what the NHTSA has done and has not yet accomplished in the V2V Technology Report in preparing to meet its CBA responsibilities.

Federal oversight of policy formation has several layers that provide guidance for the use of CBA in policy evaluation. Executive Order 12866 requires regulatory agencies to “assess both the costs and the benefits of the intended regulation and [...] propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs.”⁴⁹ The executive order, which establishes and governs the regulatory process, assigns to the OMB the responsibility to provide guidance in regulatory planning and to review individual regulations, and establishes the Office of Information and Regulatory Affairs within the OMB as “the repository of expertise concerning regulatory issues, including methodologies and procedures.”⁵⁰ OMB Circular A-4 provides guidance for regulatory analysis, and indicates CBA as the systematic framework for evaluating regulatory choices that must be carried out for major health and safety rulemakings “to the extent that valid monetary values can be assigned to the primary expected health and safety outcomes.”⁵¹ Specific DOT guidelines inform agencies on how to assign such valid monetary values to the reduction of fatalities and injuries expected to result from the adoption of health or safety regulations.⁵²

CBA is a systematic decision procedure typically used to evaluate whether a particular public project or government policy should be undertaken, or which one of multiple projects or policies should be selected. Classical examples of public projects include the construction of dams and highways and the enactment of environmental policies. The distinguishing feature of CBA—relative to private investment decision procedures—is the inclusion of all the costs and benefits arising from the particular project or projects to be evaluated. Economists refer to these as *externalities* and CBA aims to account for (that is, internalize) all relevant externalities. In fact, while a private firm makes its investment decisions ultimately guided by (private) profitability criteria that require, at a minimum, that revenues exceed costs, when considering a project or policy of public interest, a decision maker should consider all the benefits and costs that accrue to the community as a whole.

⁴⁹ Executive Order 12866, Section 1(b)(6).

⁵⁰ Executive Order 12866, Section 2(b).

⁵¹ OMB Circular A-4, p. 9.

⁵² DOT VSL Memo.

CBA is intended to inform regulatory action by measuring the overall welfare impact of public projects and policies. Welfare impact is here intended in utilitarian terms, as the “economic surplus” generated by the regulatory action. Formally, a CBA measures the net benefit of a project as the compensating monetary value—in economic parlance, the “compensating variation”—that, absent the project, would make the community members as well off as they would be with the project. In other words, a CBA estimates the monetary value of costs and benefits of a project to determine whether pursuing the project increases (or, hopefully, maximizes) welfare—all the economic costs and benefits, not just those within the mission or regulatory jurisdiction of the agency composing the CBA.⁵³

The necessary elements of a CBA analysis to evaluate the welfare impact of a particular action or set of actions are the following:

1. Specify the set of alternative actions and select an appropriate baseline;
2. Properly measure all the *economic* costs and benefits relative to the baseline;
3. Express the undiscounted economic costs and benefits in a common monetary unit and discount them to a present value (“PV”); and
4. Model uncertainty and perform sensitivity analysis.⁵⁴

Specify alternatives and select baseline. Regulatory proposals typically consider multiple alternatives. CBA is used to find the alternative or set of alternatives that maximize social welfare. In doing so, selecting a common appropriate baseline is essential. In line with the economic principles of CBA, OMB regulatory guidelines require that “[t]his baseline should be the best assessment of the way the world would look absent the proposed action.”⁵⁵ Choosing an appropriate baseline requires more than simply assuming that the world absent the regulation would resemble the present. At a minimum, the baseline “should reflect the future effect of

⁵³ For a comprehensive discussion about the foundations of CBA see, for example, Edward J. Mishan and Euston Quah, *Cost-Benefit Analysis*, Routledge, 2007; also, Matthew D. Adler and Eric A. Posner, *New Foundations of Cost-Benefit Analysis*, Harvard University Press, 2006.

⁵⁴ See, for example, Edward J. Mishan and Euston Quah, *Cost-Benefit Analysis*, Routledge, 2007. Also, Anthony E. Boardman, David H. Greenberg, Aidan R. Vining, and David L. Weimer, *Cost-Benefit Analysis: Concepts and Practice*, 2006.

⁵⁵ OMB Circular A-4, p. 15.

current government programs and policies.”⁵⁶ For example, evaluations of proposals to reform many programs, such as Social Security, recognize that the program is likely to grow absent any intervention, and measure the proposed reforms against a growing baseline. Most relevant to the case of vehicle safety technologies, “[w]hen characterizing technology changes over time, you should assess the likely technology changes that would have occurred in the absence of the regulatory action. [...] If you assume that technology will remain unchanged in the absence of regulation when technology changes are likely, then your analysis will over-state both the benefits and costs attributable to the regulation.”⁵⁷

The choice of the appropriate alternatives is also crucial to identifying a welfare-maximizing policy. CBA should consider alternative approaches to achieve the same policy objectives to determine if the action being analyzed is likely to maximize net benefits, not merely create positive benefits.⁵⁸ OMB recommends choosing reasonable alternatives and describing the reasons for choosing one alternative over another.⁵⁹ According to the OMB, a CBA “should look beyond the direct benefits and direct costs of [a] rulemaking and consider any important ancillary benefits and countervailing risks,” recognizing that “[in] some cases the mere consideration of these secondary effects may help in the generation of a superior regulatory alternative.”⁶⁰ Critically, in the context of radio-spectrum, OMB explicitly requires regulatory agencies to present an analysis that “describes, compares, and evaluates the spectrum efficiency and effectiveness for various alternatives considered” and “certifies consideration of non-spectrum dependent or commercial alternatives to meet mission/operational requirements.”⁶¹

Specify economic costs and benefits. CBA must consider *all* of the relevant costs and benefits that accrue to society. For consumers, benefits are measured as their willingness to pay (“WTP”) less the cost of the good or service being evaluated. This monetarily measures how much better off they are compared to the cost of providing the good or service. On the cost side, the regulatory agency should include all opportunity costs of the resources used, not just out-of-

⁵⁶ OMB Circular A-4, p. 15.

⁵⁷ OMB Circular A-4, p. 37.

⁵⁸ OMB Circular A-4, pp. 10-11.

⁵⁹ OMB Circular A-4, pp. 16-17.

⁶⁰ OMB Circular A-4, p. 26.

⁶¹ OMB, “Circular A-11, Subject: Preparation, Submission, and Execution of the Budget,” Revised November 2014, § 51.18.

pocket monetary costs. For example, if a policy will lead to increased pollution, the cost to society of that pollution should be included in a CBA, even if the pollution never generates any monetary payments. Regulatory rules recognize that the “[o]ppportunity cost is the appropriate concept for valuing both benefits and costs,” and that “[t]he opportunity cost of an alternative includes the value of the benefits forgone as a result of choosing that alternative.”⁶²

Express costs and benefits in common monetary units and discount to present value. To make costs and benefits accruing in different time periods and across different projects comparable, they must be translated to a common money metric and discounted to present value. Furthermore, to properly express the societal benefit of a project, the discounting procedure must reflect the opportunity cost of capital and the social rate of time preference. Together, these measure how much society values a dollar today versus a dollar tomorrow. In line with the economic principles of CBA, the OMB recognizes that “the analytically preferred method of handling temporal differences between benefits and costs is to adjust all the benefits and costs to reflect their value in equivalent units of consumption and to discount them at the rate consumers and savers would normally use in discounting future consumption benefits.”⁶³ OMB requires that real discount rates of 3 and 7 percent should be used as a base-case for regulatory analysis. The 7 percent rate is “an estimate of the average before-tax rate of return to private capital in the U.S. economy,” while the lower 3 percent rate is used to approximate the social rate of time preference for consumption.⁶⁴

Public regulation often affects the health and safety of individuals. CBA requires that costs and benefits in terms of improved safety, reduced risks and avoided fatalities are measured in monetary units to reflect the public’s willingness to pay for improvements in health and safety. OMB requires regulators to provide “a benefit-cost analysis of major health and safety rulemakings” and recognizes—in accordance with the economic principles of CBA—that, “[i]n monetizing health benefits, a WTP measure is the conceptually appropriate measure as compared to other alternatives [...]. Using the WTP measure for health and safety allows you to directly compare your results to the other benefits and costs in your analysis, which will typically be

⁶² OMB Circular A-4, pp. 18-19.

⁶³ OMB Circular A-4, p. 33.

⁶⁴ OMB Circular A-4, p. 33. OMB further suggests using discount rates higher than 7 percent “if there is reason to expect that the regulation will cause resources to be reallocated away from private investment in the corporate sector,” and recommends “using other discount rates to show the sensitivity of the estimates to the discount rate assumption.” OMB Circular A-4, pp. 33-34.

based on WTP.”⁶⁵ Specific DOT guidelines regarding the calculation of health and safety benefits arising from vehicles safety technologies and regulations will be discussed below.

Address uncertainties. The precise costs and benefits of regulatory options are not always known for certain, and a proper CBA must reflect this uncertainty. When probability distributions are available or can be developed, these should be incorporated in the analysis. Furthermore, when cost and benefit estimates depend heavily on certain assumptions, sensitivity analyses should be carried out using plausible alternative assumptions. The OMB indicates that “[m]ajor assumptions should be varied and net present value and other outcomes recomputed to determine how sensitive outcomes are to changes in the assumptions.”⁶⁶

IV. NHTSA’s Preliminary Analysis Does Not Constitute a CBA and Contains Major Flaws

The NHTSA’s preliminary estimates of the direct monetary costs and safety benefits of implementing a V2V technology mandate for passenger vehicles attempt to highlight the economic practicability of a mandate⁶⁷ and its potential for saving lives and reducing injuries. In light of this, while recognizing that “various aspects of the technology still need further investigation,”⁶⁸ and that “[m]ore research needs to be done on whether [...] Wi-Fi enabled devices can share the spectrum successfully with V2V,”⁶⁹ the NHTSA concluded that the agency has “substantially completed the work necessary to reaching”⁷⁰ a decision regarding a mandate

⁶⁵ OMB Circular A-4, p. 28. Note that the OMB Circular provides that a CBA must be prepared in addition to a cost effectiveness analysis (CEA), which focuses on measuring the costs associated with a given proposal. Specifically, both CBA and CEA “provide a systematic framework for identifying and evaluating the likely outcomes of alternative regulatory choices,” and “[a] major rulemaking should be supported by both types of analysis wherever possible” (OMB Circular A-4, p. 9).

⁶⁶ OMB, “Circular A-94, Subject: Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs,” October 29, 1992, §9.c.

⁶⁷ As noted in the report, “[u]nder the Safety Act, standards set by NHTSA must be practicable.” Practicability here refers to the requirement of economic practicability – that is, “compliance with the standard is not so burdensome [costly] so as to create a significant harm to a well-established industry.” V2V Technology Report, p. 257.

⁶⁸ V2V Technology Report, Executive Summary, p. xix. See also Appendix B, p. 300, for a detailed list of the “Research Needs” identified by the agency.

⁶⁹ V2V Technology Report, Executive Summary, p. xvii.

⁷⁰ V2V Technology Report, Executive Summary, p. xiv.

for light-duty V2V communication systems. However, as we discuss below, the economic analysis is still very preliminary, and presents several limitations which make it unsuitable to evaluate the full set of benefits and costs of a mandate under alternative uses of the 5.9 GHz band and to develop an effective proposal.

The NHTSA's analysis needs to address five major limitations before it can be used to support a proper CBA, such as required by law.

A. WRONG BASELINE

The first major limitation of the NHTSA's analysis is that it only measures the incremental costs and benefits of the technology relative to the current state of vehicle-safety technologies, regulations and outcomes, and not relative to what they would be expected to be absent a V2V mandate—which results in a substantial overstatement of the benefits from the technology. By not recognizing the improvements in vehicle safety expected absent any V2V mandates, the benefits of mandating V2V DSRC technologies are severely overstated. For example, by measuring the benefits using the 2010-2011 levels of crashes instead of recognizing expected continuing safety improvements, the NHTSA overstates the expected number of fatalities eliminated in 2058 by up to 226 percent.⁷¹

The safety of vehicles and roads should be expected to increase and many non-DSRC based driver assistance applications—existing and in development—are expected to emerge, therefore reducing the number and severity of crashes even absent V2V deployment. The NHTSA reports that between 1992 and 2010 the fatality and injury rates have declined, respectively, by 30.3 and 40.2 percent.⁷² Also, the NHTSA estimates that the implementation of electronic stability control (“ESC”) technology alone resulted in “a total of 1,144 lives saved among passenger vehicle (PV) occupants” in 2012,⁷³ and that if all passengers involved in fatal crashes had worn their seat

⁷¹ As we discuss in Section VI.A below, between 1992 and 2010, fatalities have declined by 30.3 percent—equivalent to an annualized rate of 1.99 percent. Simply adjusting the NHTSA baseline to reflect this annualized rate of decline in fatalities substantially reduces the expected benefit of mandating the technology.

⁷² <http://www-fars.nhtsa.dot.gov/Main/DidYouKnow.aspx> (accessed December 9, 2014). Occupant fatality and injury rates include motorcyclists and are computed per 100,000 population.

⁷³ NHTSA, “Traffic Safety Facts – Estimating Lives Saved by Electronic Stability Control, 2008–2012,” June 2014, p. 1.

belts “[a]n additional 3,384 lives would have been saved in 2011.”⁷⁴ In contrast, mandating V2V technology would save an expected maximum of 1,083 lives over forty years from now (and assuming no further improvements to safety technologies and regulations).⁷⁵

These trends in safety improvements are expected to continue in the future with the implementation of new regulations and the deployment of new technologies.⁷⁶ For example, there is no reason to believe, as is implicit in the NHTSA V2V analysis, that after decades of improvements in seat-belt use no improvements after 2011 will be forthcoming.⁷⁷ Furthermore, a wide array of new, sensor-based safety technologies such as blind spot monitors, forward collision and lane departure warnings, night vision, active steering and suspension, automatic emergency braking, electronic braking assistance and stability control, and numerous other technologies are dramatically improving driving safety.⁷⁸ A meaningful CBA should embed these considerations into a quantitative projection to accurately predict the incremental benefits resulting from V2V technology.

B. OPPORTUNITY COST OF SPECTRUM

Another major limitation in the NHTSA’s analysis of the costs of a V2V DSRC mandate is that the NHTSA explicitly recognized that the FCC has opened a formal proceeding to consider sharing of the 5.9 GHz band between ITS and consumer wireless broadband, but then failed to consider the opportunity costs that an ITS mandate could create by depressing or preventing the use of consumer wireless broadband in this frequency range. A CBA must take into account the

⁷⁴ NHTSA, “Traffic Safety Facts – Lives Saved in 2011 by Restraint Use and Minimum Drinking Age Laws,” December 2012, p. 1.

⁷⁵ V2V Technology Report, Table XII-19, p. 287.

⁷⁶ For example, the NHTSA projected a year-over-year 4.9 percent decline in fatalities during the first quarter of 2014 (“Early Estimate of Motor Vehicle Traffic Fatalities for the First Quarter of 2014,” NHTSA NCSA (DOT HS 812 055)). Similarly, Delphi Automotive Systems notes that existing sensor-based technologies could reduce traffic fatalities by more than 10,000 per year according to a study from the Insurance Institute of Highway Safety. See Comment of Delphi Automotive Systems to the NHTSA, pp. 1-2.

⁷⁷ In fact, according to the NHTSA seat belt use has shown an increasing trend from 60 percent in 1995 to 87 percent in 2013. Furthermore, seat belt use still varies significantly by State, and continues to be higher in the States with stricter seatbelt enforcement laws, leaving large room for regulatory improvements. NHTSA, “Traffic Safety Facts – Seat Belt Use in 2013 – Overall Results,” January 2014.

⁷⁸ For a comprehensive list of the latest safety technologies see <https://mycardoeswhat.org/> (accessed September 24, 2015), a website launched in 2015 by the National Safety Council and the University of Iowa.

economic cost of all resources used for a project. Since DSRC would use this scarce spectrum resource for communication among vehicles, the legal requirements of a CBA mean that the cost analysis must consider the value of the resource under its best alternative use. The fact that the FCC is considering permitting consumer broadband on an unlicensed basis rather than auctioning this band does not excuse the NHTSA from the need to consider the above-described opportunity cost. Whether or not an explicit payment for spectrum is made to support the V2V mandate, the spectrum is being consumed in a manner that partially or entirely excludes other uses and from a societal perspective a CBA must account for that cost. Furthermore, to determine an effective and welfare-maximizing mandate, the CBA should consider and evaluate alternative sharing scenarios for the 5.9 GHz band and the cost of foregone unlicensed use if there is no sharing at all.

More generally, a CBA should consider whether alternative, more efficient, uses of the scarce spectrum resource or even non-spectrum dependent alternatives to the technology could meet the technology's objectives and requirements. Technology companies have made several proposals to the FCC that would enable unlicensed devices to share the 5.9 GHz band with V2V applications, which would result in much more efficient and intensive use of this scarce spectrum resource. Similarly, many of the vehicle-resident sensor-based technologies on the market today already enable vehicle systems to detect threats in the environment surrounding the vehicle and warn the driver. These systems rely on radar, lidar, and cameras and do not rely at all on 5.9 GHz spectrum. Although the agency claims that V2V communication would be the sole enabler of some safety applications, the claim is not sufficiently supported.⁷⁹

C. CROWDING OUT, CROWDING IN AND OTHER EXTERNALITIES

Besides the likely improvement in the safety of cars, roads and regulations, the NHTSA's analysis does not consider the plausible externalities that the implementation of a V2V technology mandate would impose on investments in, and developments and implementation of, substitute

⁷⁹ According to the NHTSA, V2V communications offer a longer range, 360 degrees of coverage, the ability to see around corners and through other vehicles, and are not subject to the same weather, light, or cleanliness constraints associated with vehicle-resident sensors. V2V Technology Report at pp. xiv, 25-29, and 56. However, existing field trials have provided evidence that the effective range of DSRC technology might be well below the NHTSA's stated goal of 300 meters (see discussion at footnote 8), and the safety benefits arising from the two V2V applications analyzed may be achievable through existing vehicle-resident technologies augmented with wireless technologies alternative to DSRC.

and complementary vehicle-safety technologies. In fact, mandating V2V devices on new cars is likely to disincentivize car manufactures from investing in vehicle-resident technologies alternative to (and potentially more effective than) V2V safety applications, or otherwise result in the implementation of V2V applications that are already available or expected to be available through more mature vehicle-resident technologies (negative externalities).⁸⁰ Conversely, a mandate might also complement the effectiveness of existing or new features of sensor-based technologies and create incentives for car manufacturers to invest in complementary technologies that would benefit from the information made available by the basic safety messages (“BSMs”) (positive externalities).⁸¹ We acknowledge that the car and on-board equipment manufacturers have expressed conflicting opinions on whether positive or negative externalities would prevail,⁸² and that an accurate CBA should try to assess—and support with relevant facts and analyses—which one of the two impacts is more likely to emerge, or at a minimum provide sensitivity to the outcome of the CBA. The feedback effects from these externalities on innovation and patterns of redundancy, substitutability and complementarity with alternative safety technologies should be monetized—to the extent possible—as additional costs or benefits.

Trying to quantify the impact of positive and negative externalities of a mandate requires additional research, and goes beyond the scope of the current analysis. We recognize, however, that such analysis is not necessary to compare the welfare effects of a mandate under alternative

⁸⁰ The Information Technology Industry Council—an advocacy and policy organization for the world’s leading innovation companies—argues that the marketplace should decide which technologies will be most beneficial and that NHTSA should not limit innovation or crowd out other promising technologies by adopting a technology-specific mandate. According to the organization, in fact, 4G/LTE, Wi-Fi, and 5G “provide similar capabilities, which could offer many of the same features as DSRC, as well as the potential for broader and faster commercial deployment.” See Comment of Information Technology Industry Council to the NHTSA, pp. 1-3.

⁸¹ The NHTSA, for example, argues that a combined or fused system using other sensors—such as radar, lidar, and cameras—along with V2V “would be able to use multiple sensors to augment accuracy, and could lead to improved warning timing and a reduction in the number of false positives.” V2V Technology Report, p. 28.

⁸² Mercedes Benz, for example, recognizes that DSRC might be complementary to existing on-board devices, but if prematurely mandated it could disrupt the implementation of safety systems that utilize existing on-board sensors. See Comment of Mercedes Benz to the NHTSA, p. 11. Conversely, Delphi Automotive Systems—a global supplier of passenger vehicle safety equipment—asserts that V2V is a complement to existing technologies and will not hinder the development of autonomous driving. See Comment of Delphi Automotive Systems to the NHTSA, p. 11.

scenarios if the externalities do not vary with the alternative considered or one of the alternatives dominates the others. In our analysis presented below we do not explicitly account for externalities and compare exclusive DSRC use of the 5.9 GHz band to an alternative sharing scenario in which Wi-Fi and DSRC would share the first 45 MHz of the band. Since both alternatives include mandated DSRC, the externalities identified here would be largely the same.

D. PRESENT VALUE OF MONETIZED BENEFITS

Another major limitation of the NHTSA's analysis is that in measuring the benefits of the proposed mandate, the NHTSA only computes the undiscounted annual benefits from the technology in terms of crashes avoided, lives saved, and injuries and damages avoided without attempting to monetize these benefits. However, the benefits from a mandate must be monetized and discounted to present value in a meaningful CBA. Although it might seem controversial to include the "value of lives" in a monetary calculation, it is an issue that must be addressed in a CBA.⁸³ The DOT has provided "guidance on valuing reduction of fatalities and injuries by regulations" since 1993.⁸⁴ According to the DOT, the benefit of preventing a fatality should be "measured by what is conventionally called the Value of a Statistical Life (VSL), defined as the additional cost that individuals would be willing to bear for improvements in safety (that is, reductions in risks) that, in the aggregate, reduce the expected number of fatalities by one."⁸⁵

E. INACCURATE MODELING ASSUMPTIONS

In addition to the major limitations discussed above, we believe that the NHTSA's analysis is still very preliminary and suffers from many additional potential inaccuracies. For example, the benefit analysis assumes that two vehicles equipped with a V2V device communicate with 100 percent probability and ignores the possibility of failure or miscommunication among vehicles.⁸⁶

⁸³ The controversy typically disappears when we recognize that the value that is being measured is the value *of an improvement to safety* that is expected to reduce the number of fatalities by one, and not the worth of a human life.

⁸⁴ DOT VSL Memo.

⁸⁵ DOT VSL Memo, p. 1.

⁸⁶ As the NHTSA has recognized, this is a very real concern. The NHTSA has noted the need for further testing of the accuracy of GPS information, for example, to ensure that "the DSRC unit itself is able to receive and transmit the needed messages as timely as needed and without being compromised" (V2V Technology Report, p. 56). NHTSA has also noted the need for further research and testing regarding

Continued on next page

The benefit analysis also uses an overly simplistic pattern for the diffusion of the technology benefits. The benefits are in fact estimated without taking into account the age of vehicles, and the geographic and demographic diffusion of the technology.⁸⁷ Additionally, the cost analysis does not consider the replacement costs for broken or defective devices out of warranty, or the costs associated with software updates necessary to keep the devices current. Finally, the analysis does not provide support for the chosen implementation scenarios, and does not present reasonable sensitivity analysis with respect to most inputs, including discount rates, equipment costs, fuel economy, and simulation results.

V. Efficient Sharing and Opportunity Cost of the Spectrum in the 5.9 GHz Band

In its ANPRM, the NHTSA invited comments on whether unlicensed Wi-Fi technologies would interfere with V2V communications and asked advice on how to evaluate the opportunity cost associated with forgone alternative uses of the spectrum.⁸⁸ As a key component of the larger CBA, this section answers that invitation, focusing on the benefits and costs associated with sharing a portion of the 5.9 GHz band with unlicensed users, including Wi-Fi.

A. EFFICIENT SHARING OF THE SPECTRUM IN THE 5.9 GHz BAND

The following analysis is designed to contrast and compare an implementation of the technology assigning the full 75 MHz of spectrum for exclusive DSRC use as currently envisioned by the NHTSA, to an alternative scenario that shares the spectrum resource. In fact, the available information is sufficient to establish that an efficient sharing of the spectrum, one that would maximize the value of the spectrum and at the same time achieve the full benefits of the mandate, is possible.

V2V safety applications such as the IMA and LTA require low latency and rely on the transmission of BSMs across vehicles to activate vehicle safety warnings in potential crash

Continued from previous page

message congestion among DSRC messages that might prevent basic safety messages from being received (V2V Technology Report, p. 55).

⁸⁷ Note that car safety, crash probabilities and the severity of crashes likely correlate with age of vehicles, income, geography and other demographics. Data are available to estimate such correlations and embed them into a more comprehensive analysis of the benefits.

⁸⁸ ANPRM, Section II.18.

situations. As currently envisioned, the 75 MHz of wireless spectrum are “divided into seven non-overlapping 10 MHz channels”⁸⁹ plus 5 MHz at the lower end of the band “reserved to accommodate future, unforeseen developments”⁹⁰ as shown in Table 1 below. The DSRC unit would operate with two radios, each one tuned to one channel at a time. For the currently planned implementation, V2V safety warning services would be provided in a single 10 MHz channel—channel 172—while a central channel—channel 178—would broadcast the availability of other services provided on the remaining channels.

In other words, the core functionality of DSRC—the one that generates all of the safety benefits estimated by the NHTSA and for which low latency is necessary—only requires 20 MHz of spectrum, a single 10 MHz communications channel plus a 10 MHz control channel.⁹¹ Conversely, the remaining channels would be used for ancillary services (*e.g.* revocation lists, map delivery, toll and fee collection, and advertisement or other content delivery) that are much less time-sensitive, and are not unique to DSRC.⁹² The higher latency tolerance of these additional services “implies significant flexibility for coexistence purposes,” and “[s]ince DSRC transmits in 100 millisecond intervals and operates on a fault-tolerant retransmission basis, over several seconds a message can be transmitted dozens of times, greatly enhancing the probability of successful communication.”⁹³

⁸⁹ V2V Technology Report, p. 92.

⁹⁰ FCC 03-324, Report and Order, In the Matter of WT Docket No. 01-90, ET Docket No. 98-95, and RM-9096, adopted December 17, 2003 and released February 10, 2004, p. 18 ¶ 27 (2003).

⁹¹ Note that under the planned implementation DSRCs public safety communications have access priority over all other DSRC communications subject to a control channel priority system management strategy, 47 C.F.R. § 90.377(d).

⁹² Note that most safety applications only require the BSM to activate warnings. In fact, “a catalogue of potential V2I safety-ancillary applications was presented recently by DSRC stakeholders in IEEE discussions, but close examination reveals many of these applications to be in fact core functions enabled by BSMs.” Rob Alderfer, Dirk Grunwald, and Kenneth Baker, “Optimizing DSRC Safety Efficacy and Spectrum Utility in the 5.9 GHz Band,” 2014, p. 11.

⁹³ Rob Alderfer, Dirk Grunwald, Kenneth Baker, “Optimizing DSRC Safety Efficacy and Spectrum Utility in the 5.9 GHz Band,” 2014, p.13.

Table 1: Current Band Plan for DSRC Channel Spectrum

Channel No.	Frequency Range (MHz)	Channel use
170	5850-5855	Reserved
172	5855-5865	Service Channel
174	5865-5875	Service Channel
175	5865-5885	Service Channel
176	5875-5885	Service Channel
178	5885-5895	Control Channel
180	5895-5905	Service Channel
181	5895-5915	Service Channel
182	5905-5915	Service Channel
184	5915-5925	Service Channel

Source: 47 C.F.R. § 95.1511(a).

What the discussion above implies is that V2V safety services only require a 10 MHz channel to operate, and not the entire 75 MHz of the 5.9 GHz band. As a conservative estimate, even with two 10 MHz channels for safety-of-life traffic and one 10 MHz control channel, the spectrum required to execute the NHTSA’s ANPRM, plus room to grow for new safety technologies, requires only 30 MHz of spectrum. Conversely, the other non-safety-related DSRC services do not require low latency for safety of life functionality, and could share the spectrum with unlicensed Wi-Fi without diminishing any of the measured safety benefits.

Two alternative plans have been advanced for shared use of the 5.9 GHz band. Under a plan originally proposed by Qualcomm,⁹⁴ Wi-Fi would only share the lower 45 MHz portion of the band with DSRC devices, where it would be required to protect DSRC from harmful interference.⁹⁵ The upper 30 MHz would be reserved exclusively for the use of safety-of-life DSRC operations, like the V2V basic safety messages contemplated in NHTSA’s V2V report.⁹⁶

⁹⁴ Tevfik Yucek, Eldad Perahia, Vinko Erceg, and Xinzhou Wu, “Proposal for U-NII 4 band coexistence,” Qualcomm, Doc. IEEE 802.11-13/1449r2, 2013, available at <https://mentor.ieee.org/802.11/dcn/13/11-13-1449-02-0reg-proposal-for-dsrc-band-coexistence.pptx> (accessed November 30, 2015). Hereinafter, “Qualcomm Proposal.”

⁹⁵ Specifically, according to the proposal, U-NII devices would be allowed to use the lower 45MHz of the 5.9 GHz band provided that they satisfy the “spectral leakage requirements” and “implement ‘listen before talk’ rules based on 802.11 20 MHz detection levels.” Qualcomm Proposal, p. 4.

⁹⁶ Qualcomm Proposal, p. 4.

Under the plan proposed by Cisco, Wi-Fi would be allowed to use the entire 5.9 GHz band, but only through a listen-detect-and-avoid protocol.⁹⁷

While identifying the optimal sharing scenario goes beyond the scope of this report and requires further research, in our CBA of a V2V DSRC mandate we have chosen to compare implementation of the mandate assigning the full 75 MHz of spectrum for exclusive DSRC use to an alternative scenario that conservatively provides for exclusive DSRC use of the upper 30 MHz of the 5.9 GHz band, while unlicensed Wi-Fi would be authorized to share the lower 45 MHz of the 5.9 GHz band, in line with the Qualcomm proposal. The proposal would capture the full safety benefits of V2V technology and at the same time promote efficient use of the scarce spectrum. In fact, for reasons we discuss below, most of the value of unlicensed use of the 5.9 GHz band would come from the first 45 MHz of band. Conversely, while the Cisco proposal would allow shared use of the entire 75 MHz of spectrum, depending upon implementation, the limitations imposed could greatly diminish the usability of the spectrum for widespread Wi-Fi operations.

B. VALUE AND OPPORTUNITY COST OF THE SPECTRUM IN THE 5.9 GHz BAND

A number of studies have recently focused on estimating the total value of unlicensed spectrum in the U.S., and unlicensed Wi-Fi in particular, by calculating the value of economic activity that would be lost absent unlicensed spectrum designations.⁹⁸ These approaches, however, only provide an estimate of associated value tied to existing designations overall. Instead, we are interested in an estimate of the value of a specific new, incremental unlicensed spectrum designation.

⁹⁷ Peter Ecclesine, Cisco Systems, “Proposal for 5850-5925 MHz unlicensed devices,” Doc. IEEE 802.11-13/0994r0, Aug. 28, 2013, available at <https://mentor.ieee.org/802.11/dcn/13/11-13-0994-00-0reg-proposal-for-U-NII-4-devices.docx> (accessed November 30, 2015).

⁹⁸ See, for example, Paul Milgrom, Jonathan Levin and Assaf Eilat, “The Case for Unlicensed Spectrum,” Stanford Institute for Economic Policy Research, 2011. Also, Mark Cooper, “Efficiency Gains and Consumer Benefits of Unlicensed Access to the Public Airwaves: The Dramatic Success of Combining Market Principles and Shared Access,” University of Colorado, Boulder, 2012; Richard Thanki, “The Economic Value Generated by Current and Future Allocations of Unlicensed Spectrum,” 2009; Richard Thanki, “The Economic Significance of Licence-Exempt Spectrum to the Future of the Internet,” 2012; Raul Katz, “Assessment of the Economic Value of Unlicensed Spectrum in the United States,” 2014.

Measuring the value of a new unlicensed spectrum designation is different from calculating the value of licensed spectrum. Since unlicensed spectrum is not traded in markets, its value must be indirectly estimated. Moreover, valuing a new unlicensed spectrum designation has several complicating factors. First, an additional designation both increases the value of existing uses and creates the potential for new valuable uses. While marginal uses due to additional spectrum are likely worth less than the average, non-marginal uses can be worth significantly more.⁹⁹ Second, the value of an additional designation crucially depends on whether use of the available unlicensed spectrum is congested or not. Third, use and congestion in unlicensed Wi-Fi both depend on the throughput capacity of the network, which in turn depends on the transmission technologies employed by the end users as well as the bandwidth available for unlicensed use. In what follows we conservatively measure the value of sharing the lower 45 MHz of the 75 MHz of spectrum in the 5.9 GHz band as the opportunity cost of not allowing Wi-Fi devices to share the band. While other unlicensed applications would in principle benefit from a new unlicensed designation, unlicensed Wi-Fi would likely capture the lion's share of the additional value.¹⁰⁰

Several reasons make the 5.9 GHz band very valuable for unlicensed Wi-Fi. While Wi-Fi standards historically used the 2.4 GHz ISM band as the primary band for Wi-Fi service, the 5 GHz band has become increasingly important because of the limited bandwidth available at 2.4 GHz, interference and potential congestion caused by other devices sharing the spectrum at 2.4 GHz with Wi-Fi, and the continuous increase in demand for Wi-Fi data traffic.¹⁰¹ Most devices

⁹⁹ In a marginal analysis, additional generic spectrum would likely be worth less than the average value of existing unlicensed spectrum because the most valuable uses of unlicensed spectrum would be expected to be deployed first, leaving the value of adding more spectrum to bring down the average value of unlicensed spectrum. This is an example of the broader phenomenon of diminishing returns. When new (non-marginal) uses are added to the equation, however, the diminishing returns result need not hold.

¹⁰⁰ We do not directly address LTE-U. If LTE-U works as its proponents envision, it would have two off-setting impacts on the analysis here. First, to the extent it carries traffic that otherwise would have been carried by Wi-Fi, it simply substitutes for Wi-Fi capacity. Second, to the extent it carries additional traffic and/or traffic that would have been carried on licensed frequencies, it exacerbates likely congestion and increases the impacts measured herein. If it does not work as proposed, these two impacts would still exist, but there would be less residual capacity for Wi-Fi.

¹⁰¹ As a practical matter, unlicensed Wi-Fi in the 2.4 GHz band can only use three non-overlapping 20 MHz channels in the U.S. (channels 1, 6, and 11) and on a shared-basis with a wide array of devices using that band such as microwaves, ISM devices, security cameras, cordless phones and Bluetooth devices. The large number of devices operating the band significantly increases the probability of interference and Wi-Fi service degradation. Although "co-channel" and "adjacent channel" interference among Wi-Fi networks may also occur, interference is most likely to come from devices

Continued on next page

on the market today already contain 5 GHz radios, and the latest Wi-Fi standard, IEEE 802.11ac, is designed to work only in the 5 GHz band.¹⁰² As a result, the 5 GHz band is the prime band that can offer added Wi-Fi capacity in the near future. Additionally, adjacency of the 5.8 GHz or “U-NII 3” band to the 5.9 GHz band offers a unique avenue to fully exploit the latest 802.11ac Wi-Fi standard. The standard utilizes 80 or 160 MHz channels and allows speeds of over 1 Gigabit per second (Gbps).¹⁰³ Unlicensed sharing of the 5.9 GHz band is in fact the only path to a contiguous 160 MHz channel and additional non-contiguous 160 MHz channels.¹⁰⁴

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that do not work cooperatively with Wi-Fi and result in significant loss of throughput. Closely related to interference, network congestion is likely to occur when the Wi-Fi channels become heavily utilized. Jardoash et al. (2005), for example, estimate that at high levels of channel utilization, the overall amount of data which can be transferred decreases with an increase in the amount of time the channel is busy. Amit P. Jardoash, Kevin C. Almeroth Elizabeth M. Belding-Royer, “Understanding Congestion in IEEE 802.11b Wireless Networks, 2005. Several authors have also suggested that widespread unlicensed network congestion is likely to occur at 2.4 GHz, especially in public places and dense urban environments. Alderfer (2013), for example, used reasonable forecasts of Wi-Fi traffic growth, network density, and technology efficiency to suggest that there is a clear need for more Wi-Fi spectrum. Rob Alderfer, “Wi-Fi Spectrum: Exhaust Looms,” 2013, p. 21.

¹⁰² See Vivian Kelly, New IEEE 802.11ac Specification Driven by Evolving Market Need for Higher, Multi-User Throughput in Wireless LANs,” January 7, 2014, available at http://standards.ieee.org/news/2014/ieee_802_11ac_ballot.html (accessed November 30, 2015). The standard, explicitly intended to meet the increasing demand for higher transfer speed and to enable new data-intensive wireless applications, has seen wide adoption in the U.S. since 2013. For instance, all latest Mac desktops, notebooks and iPhones are equipped with 802.11ac. See, <http://store.apple.com/us/mac/compare> and <http://www.apple.com/iphone/compare/> (accessed June 24, 2015). See also, Gordon Kelly, “802.11ac vs 802.11n: What’s The Difference?” Forbes, December 30, 2014, available at <http://www.forbes.com/sites/gordonkelly/2014/12/30/802-11ac-vs-802-11n-Wi-Fi-whats-the-difference/> (accessed June 24, 2015).

¹⁰³ According to the Institute of Electrical and Electronics Engineers (“IEEE”), the standard, designed to work only in the 5 GHz band, is theoretically capable of providing data rates up to 7 Gbps, and is expected to bring Wi-Fi speeds of at least 1 Gbps to consumers. The standard uses wider bandwidths of contiguous and non-contiguous 80 and 160 MHz channels, higher order modulation, and up to eight spatial streams, leading to faster and more efficient data transfer and in turn, increased battery life. The standard also supports multiple concurrent downlink transmissions—referred to as “multi-user multiple-input, multiple-output,” or “MIMO”—enabling more efficient spectrum use, higher capacity and up to four simultaneous user transmissions. See Vivian Kelly, New IEEE 802.11ac Specification Driven by Evolving Market Need for Higher, Multi-User Throughput in Wireless LANs,” January 7, 2014, available at http://standards.ieee.org/news/2014/ieee_802_11ac_ballot.html (accessed November 30, 2015).

¹⁰⁴ See “Operation in U-NII Bands - 802.11 Channel Plan §15.407 (Part 15E), 1st R&O (FCC 06-96), effective 6/2/2014,” available at <https://apps.fcc.gov/kdb/GetAttachment.html?id=lp4w3WTVG9PReWNFG0ckTg%3D%3D> (accessed

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The value generated by additional spectrum for Wi-Fi in the 5.9 GHz band can be broken down into three main, additively separable components:

1. The increased value of existing uses generated by reduced congestion, improved quality, speed and reliability.
2. The value generated by new uses that would emerge because of a higher throughput capacity.
3. The value generated by spillover effects on innovation and technology adoption coming from new and improved, potential and existing uses.

Existing Uses. The first component of value of additional spectrum for Wi-Fi at the 5.9 GHz band is the incremental value generated by reduced congestion, improved quality, speed and reliability of Wi-Fi existing uses. While more than 500 MHz of spectrum are designated as unlicensed in the 5 GHz band, use of a large portion of this spectrum is restricted by power limits and dynamic frequency selection (“DFS”) requirements, rendering significantly less spectrum effectively usable for most Wi-Fi operations.¹⁰⁵ The portions of the 5 GHz band currently usable for unlicensed Wi-Fi include the U-NII 1 (5150-5250 MHz) and U-NII 3 (5725-5850 MHz) bands. However, due to the Wi-Fi channelization scheme, not all of the spectrum available in these two bands is actually used for Wi-Fi. This is because in U-NII 1 the first Wi-Fi channel begins at 5170 MHz, meaning that only 80 out of 100 MHz are used for Wi-Fi, while in U-NII 3 the first Wi-Fi channel begins at 5735 MHz and the last 20 MHz Wi-Fi channel ends at 5835 MHz, meaning that only 100 out of 125 MHz are actually used for Wi-Fi.¹⁰⁶ In other words, two

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September 22, 2015). Hereinafter, “802.11 Channel Plan.” Note that a contiguous 160 MHz channel is theoretically available under the current FCC rules at channel 50 (5170-5330 MHz) in the U-NII 1 and U-NII 2 bands. However, due to power limits and dynamic frequency selection requirements in the U-NII 2 band only one non-contiguous 160 MHz channel encompassing channels 42 (5170-5250 MHz) and 155 (5735-5815 MHz) in the U-NII 1 and U-NII 3 bands, respectively, can be effectively used for Wi-Fi operations.

¹⁰⁵ Under the current FCC rules, the U-NII 2A (5250-5350 MHz) and U-NII 2C (5470-5725 MHz) bands have a low power limit of 250 mW (compared to 1 W in the widely used portions of the 5 GHz band) and the technical rules for operation in these bands require the use of dynamic frequency selection in order to protect incumbent operations. See 47 C.F.R. § 15.407(a)(2), (h).

¹⁰⁶ 802.11 Channel Plan.

80 MHz channels and one 20 MHz channel are currently available at 5 GHz.¹⁰⁷ The value of sharing the lower 45 MHz of the 5.9 GHz band with Wi-Fi can therefore be seen as the value of adding a third 80 MHz Wi-Fi channel (5815-5895 MHz) and the first contiguous 160 MHz Wi-Fi channel (5735-5895 MHz). The addition would increase the capacity of a 5 GHz unlicensed Wi-Fi network by at least 33.3 percent.¹⁰⁸

Existing studies estimate that the welfare contribution of residential Wi-Fi alone ranges between \$36 and \$38 billion yearly at current demand levels.¹⁰⁹ These numbers may be plausible given that over 80 million households have broadband connection today in the U.S.¹¹⁰ and pay \$750 per year¹¹¹ for internet connectivity, suggesting expenditures exceeding \$60 billion per year. The consumer welfare from residential Wi-Fi estimated in those studies is then slightly less than 2/3

¹⁰⁷ Or, alternatively, four 40 MHz channels and one 20 MHz channel, nine 20 MHz channels, or a combination of the above.

¹⁰⁸ Assuming that users today have access to two 80 MHz channels and one 20 MHz channel in the 5 GHz band, and that with the additional 45 MHz of U-NII 4 spectrum they would have access to three 80 MHz channels, sharing the 5.9 GHz band would increase the available channel bandwidth by 33.3 percent (from 180 MHz = 2 * 80 MHz plus 20 MHz to 240 MHz = 3 * 80 MHz). The overall Wi-Fi network capacity would increase even further due to the higher throughput efficiency of 80 MHz channels under the 802.11ac standard. See “IEEE Standard for information technology- Specific requirements, Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, Amendment 4: Enhancements for Very High Throughput for Operation in Bands below 6 GHz,” Tables 22-30 through 22-61, pp. 323-339.

¹⁰⁹ Mark Cooper, “Efficiency Gains and Consumer Benefits of Unlicensed Access to the Public Airwaves: The Dramatic Success of Combining Market Principles and Shared Access,” University of Colorado, Boulder, 2012, p. 20; and Raul Katz, “Assessment of the Economic Value of Unlicensed Spectrum in the United States,” 2014, p. 11.

¹¹⁰ As of 2013, broadband penetration in the U.S. was estimated at 70 percent, implying that over 80 million households had broadband connectivity out of 115 million households reported from the census. See “Broadband by the Numbers: An Internet Built for All: Fast, Affordable and Competitive,” NCTA, available at <https://www.ncta.com/broadband-by-the-numbers> (accessed September 23, 2015). The International Telecommunication Union of the United Nations reports that in 2014 there were 97,981,000 fixed broadband subscriptions in the U.S. Fixed-broadband subscriptions 2000-2014,” International Telecommunication Union, available at https://www.itu.int/en/ITU-D/Statistics/Documents/statistics/2015/Fixed_broadband_2000-2014.xls (accessed September 23, 2015).

¹¹¹ That is, based on an average price of \$62.50, the midpoint of an estimated range of \$60 to \$65. Andrew Burger, “Report: Average U.S. Broadband Prices Are Below World Average of \$76.61,” April 30, 2014, available at <http://www.telecompetitor.com/report-average-u-s-broadband-prices-are-below-world-average-of-76-61/> (accessed September 23, 2015).

of the expenditures on residential broadband,¹¹² which suggests that the ability to connect wirelessly to broadband in the home is a significant component of the value of broadband.

While the reduced interference at 5 GHz relative to the 2.4 GHz band, and the improved quality, speed and reliability of services due to the added capacity already warrant significant value, a critical contributor of the value of additional unlicensed spectrum is congestion relief in densely populated environments. Adding capacity in a congested environment will in fact tremendously improve the quality and reliability of service, thus suggesting a marginal value that is higher than the average at least for the congested areas.

In Appendix B, we show that congestion in residential Wi-Fi is likely to occur in densely populated areas even if all devices were using the latest IEEE 802.11ac standard in the near future,¹¹³ and that sharing the lower portion of the 5.9 GHz band would relieve a non-trivial portion of the congested areas. Specifically, according to our analysis, congestion could plausibly occur in areas representing 14.5 percent of the U.S. population at current demand levels, and up to 32.6 percent of the U.S. population doubling the current demand level.¹¹⁴ In these scenarios, shared use of the 5.9 GHz band would alleviate congestion for between 4.8 and 10 percent of the U.S. population at current and future demand levels, respectively.¹¹⁵ Although the proportion of

¹¹² From an estimated welfare contribution of \$38 billion and expenditures exceeding \$60 billion we get $\$38 \text{ billion} / \$60 \text{ billion} = 63.3\%$, or slightly less than 2/3.

¹¹³ Note that under the currently available technologies the actual throughput capacity of the system is significantly lower than if all devices were using the latest IEEE 802.11ac standard. Actual congestion is therefore likely to be more severe than modeled in Appendix B.

¹¹⁴ See Appendix B. Our analysis considers contention areas of 100 meters by 100 meters and looks at tract level population density from the census to establish whether household demand for throughput is likely to exceed the actual throughput capacity of the system. Along with the contention area, a key parameter in the analysis is the efficiency of the system—that is, the system’s actual throughput divided by the maximum theoretical throughput. We also performed sensitivities using different values of the efficiency parameter and contention area assumptions, yielding qualitatively similar results. Restricting the contention area to 50 meters by 50 meters cells substantially reduces the percentage of U.S. population that would likely experience congestion. However, we believe that our population density thresholds for congestions are likely to be conservative. In fact, population density is unlikely to be uniform, and the actual density around large buildings and building blocks is likely to be much higher than the tract’s average.

¹¹⁵ See Appendix B. Note that according to Cisco projections, total IP traffic in North America will grow three-fold from 2014 to 2019, while the average traffic per user will grow by 172 percent. “VNI Forecast Highlights,” Cisco Systems, available at

the U.S. population that may experience congestion in the near future varies with alternative assumptions about the efficiency of Wi-Fi networks in congested environments and the size of the contention area for a hotspot, the benefits of sharing the 5.9 GHz band are fairly consistent at about a 30% improvement. Furthermore, even in areas that would continue to experience congestion with the additional frequencies, the quality and reliability of service will increase. This predicted congestion relief would come in densely populated urban areas with the heaviest Wi-Fi use, and there is no reason to believe these areas are below average in the value generated by Wi-Fi (and to the extent they represent higher income areas or areas of higher technology adoption, they would be above average). Consequently, we apportion value in line with the impacted population. Added value on residential Wi-Fi, however, is only part of the added value from added capacity, as congestion is very likely to occur today in stadiums and crowded public places that would also greatly benefit from additional Wi-Fi spectrum to relieve congestion.

For the purposes of the current analysis, we assume the added value from added capacity on existing uses at between \$5 and \$10 billion¹¹⁶ yearly—roughly between 13 to 28 percent of the values estimated for the welfare contribution of residential Wi-Fi alone. We believe these to be reasonable, conservative, values. Sharing the lower 45 MHz of the 5.9 GHz band would in fact increase the network capacity at 5 GHz by more than 33.3 percent, providing congestion relief or improving the quality and reliability of residential Wi-Fi in areas representing between 14.5 and 32.6 percent of the U.S. population as consumer demand for data continues to increase.

New Uses. Reduced congestion, added capacity, speed and reliability are generally expected to create new uses of unlicensed Wi-Fi. This is particularly true when the added capacity comes from sharing additional spectrum at 5.9 GHz. With the availability of contiguous and non-contiguous 160 MHz channels, the 802.11ac standard is expected to favor the emergence and diffusion of high-bandwidth applications like true HD video streaming and bandwidth-intensive video and voice applications, graphic-intensive online gaming, real-time synchronization and data backup, web and cloud based computing, and manufacturing floor automation. It will also be effective for outdoor Wi-Fi network deployments in user-dense environments like stadiums and arenas, as it will support larger numbers of users at higher speeds.

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http://www.cisco.com/web/solutions/sp/vni/vni_forecast_highlights/index.html (accessed September 23, 2015).

¹¹⁶ The estimates provided in this subsection are intentionally presented in rounded numbers so as not to provide a false sense of precision.

The value of enabling a new class of Wi-Fi uses is the economic contribution expected from these uses. While it is difficult—and beyond the scope of the current report—to predict precisely how much additional benefit will be derived from enabling new, higher bandwidth applications, we expect the value of these applications to be significant. Although significant further analysis would be required to estimate the value from new uses, absent information on the relative size of the marginal and non-marginal benefits we bound this value by the added value on existing uses and assume that new uses could contribute between \$5 billion to \$10 billion per year in additional value.

Spillover Effects. The third component of value, and perhaps the hardest to measure, comes from spillover effects on innovation and technology adoption which may create substantial economic surplus in other domains. For example, unlicensed spectrum technologies such as Wi-Fi already “off-load” data traffic from cellular networks and translate into a higher surplus for both consumers and licensed wireless network providers.¹¹⁷ Added unlicensed spectrum capacity may further increase the welfare contribution of cellular data off-loading, particularly so as demand for data traffic continues to increase. Although spillover effects could potentially create substantial economic surplus, we conservatively do not place a monetary value for these in our analysis.

Combining the incremental value that the additional 45 MHz of spectrum at 5.9 GHz would generate from existing and future uses, we estimate the plausible annual opportunity cost of spectrum sharing in the range of \$10 billion to \$20 billion.¹¹⁸

¹¹⁷ Cisco, for example, estimates that 1.2 exabytes of mobile data traffic, 45 percent of the total, were off-loaded in 2014, and predicts that mobile offload will increase to 28.9 exabytes per month, or 54 percent, by 2019. “Cisco Visual Networking Index (VNI) Forecast: Mobile Data Traffic Update, 2014-2019,” Cisco, 2015, p. 22. For a summary of estimates found in the literature see, for example, Raul Katz, “Assessment of the Economic Value of Unlicensed Spectrum in the United States,” 2014, p. 13, Figure E.

¹¹⁸ It is worth noting the implications of this valuation on a \$/MHz-pop basis. The calculation requires translating the annual revenue estimates into a single present value and a number of additional assumptions. First, this value is associated with at least 60 MHz of additional capacity (that is, the capacity of three additional 20 MHz channels), but possibly as much as 160 MHz (the capacity of an additional 160 MHz channels). Second, only the appropriate share of the value created that should be allocated to the spectrum resource. In estimating the value of licensed spectrum, for example, 15 to 20 percent of revenues are often allocated to residual profits. Finally, an appropriate discount rate must be calculated, but would likely fall within a range of 5 to 10 percent. Using these ranges of parameters—60 MHz to 160 MHz of added capacity, 15% to 20% of residual profits, 5% to 10%

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VI. CBA of a Mandate on V2V

In this section we complement and adjust the NHTSA’s analysis to construct an initial measure of the welfare effect of mandating DSRC. Before presenting our results, we discuss each of the proposed adjustments and the assumptions made.

A. TRENDS IN CRASHES, FATALITIES AND INJURIES

The NHTSA’s analysis improperly assumes that the target population of crashes throughout the implementation period would stay constant at the 2010-2011 level. However the 2010-2011 levels do not provide a reasonable baseline—crash rates have been declining for decades and no evidence was provided to suggest that trend would abruptly stop. We adjust the NHTSA’s analysis by reducing the yearly number of lives saved and injuries or damages avoided using NHTSA’s own data on past trends in fatalities, injuries and property damaged only vehicles (“PDOVs”).¹¹⁹ Specifically, we assume that fatalities, injuries, and PDOVs are expected to decrease at annual rates of, respectively, 2.48, 2.86 and 1.18 percent. These numbers reflect the annualized rates of decline in fatalities, injuries and PDOVs between 2001 and 2010.¹²⁰

Once trends are taken into account, the benefits of a V2V mandate are dramatically reduced. This is clearly illustrated in Figure 1 below comparing the baseline number of fatalities and the number of fatalities eliminated over the implementation period under the NHTSA high scenario before and after we account for the trend. As can be seen from the figure, by ignoring the

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discount rate—to our estimated range of value of \$10 billion to \$20 billion suggests a range of spectrum values from a low of \$0.30/MHz-pop to a high of \$4.27/MHz-pop.

¹¹⁹ We are here implicitly assuming that as the overall number of crashes, fatalities and injuries decreases, the safety benefit of the technology will decrease proportionally.

¹²⁰ Between 2001 and 2010, fatalities have declined by 20.2 percent—equivalent to an annualized rate of 2.48 percent—while injuries have declined by 23.0 percent—equivalent to an annualized rate of 2.86 percent. Similarly, PDOV have declined by 10.2 percent—equivalent to an annualized rate of 1.18 percent. See “Fatality Analysis Reporting System General Estimates System: 2010 Data Summary,” U.S. Department of Transportation, NHTSA, Exhibit 2, p. 4. Hereinafter “NHTSA 2010 Data Summary.” Note that over the same time period, fatalities and injuries on passenger vehicles—that is, only including passenger cars and light trucks, excluding motorcycles and trucks—decreased even more, respectively by 30.8 and 28.8 percent, or 4.0 and 3.7 percent annually. NHTSA 2010 Data Summary, Exhibits 5-6, pp. 7-8.

expected trends in fatalities, the NHTSA overstates the number of fatalities eliminated by 226 percent.

Figure 1: Benefits of V2V Accounting for Trends in Fatalities

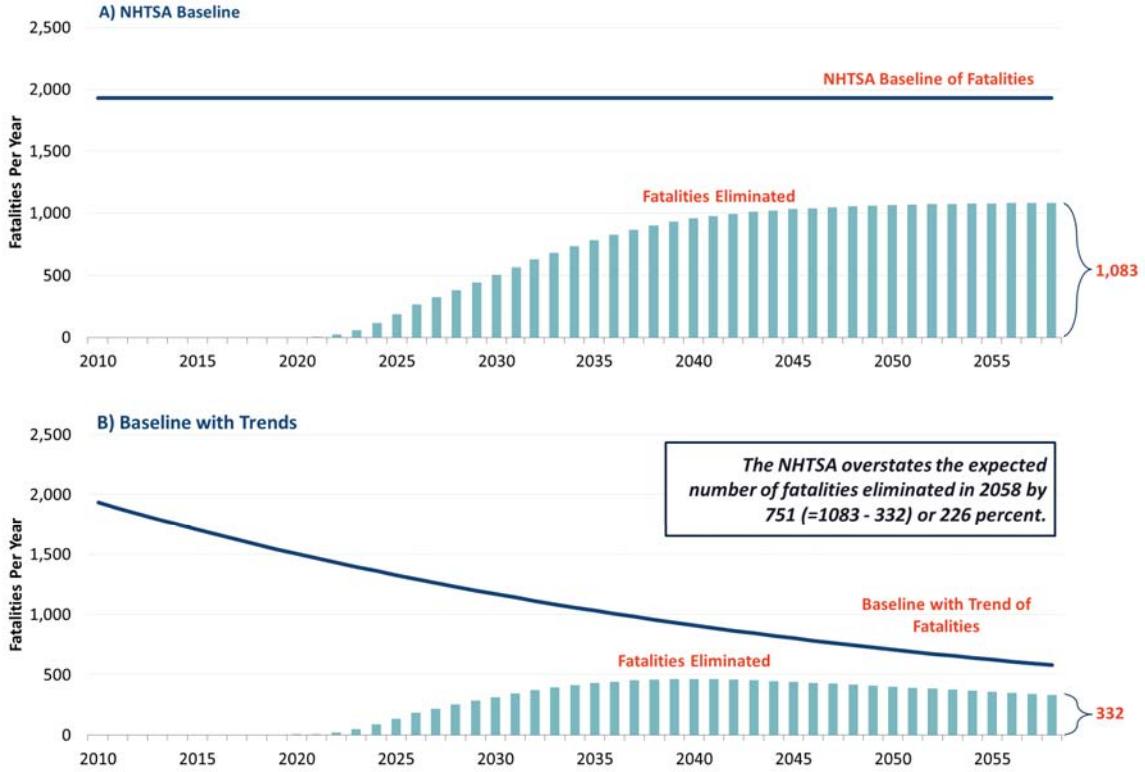


Table 2 below illustrates the overall impact that properly accounting for trends has on the expected number of fatalities, injuries, and PDOVs avoided as a result of V2V under the first implementation scenario. As reported in Table 2, once we account for trends, the expected number of fatalities eliminated under the most optimistic scenario in 2058 would decrease from 1,083 to 332—a reduction of 69.3 percent—while the expected number of injuries avoided in 2058 would decrease from 270,011 to 68,890—a reduction of 74.5 percent.

Table 2: Benefits of V2V Accounting for Trends in Crashes, Fatalities and Injuries

Calendar Year	Scenario		2020	2030	2040	2050	2058
NHTSA Baseline - 2010 - 2011 Population of Crashes							
Fatalities Eliminated	Low	[1]	0.47	363	687	765	777
	High	[2]	0.65	507	958	1,067	1,083
MAIS 1-5 Injuries	Low	[3]	115	89,425	169,156	188,353	191,202
	High	[4]	162	126,284	238,879	265,988	270,011
PDOV	Low	[5]	307	239,050	452,186	503,502	511,118
	High	[6]	437	340,567	644,215	717,323	728,173
Baseline Including Trends in Crashes							
Fatalities Eliminated	Low	[7]	0.37	225	332	287	238
	High	[8]	0.52	314	462	400	332
MAIS 1-5 Injuries	Low	[9]	89	51,481	72,821	60,635	48,783
	High	[10]	125	72,700	102,836	85,627	68,890
PDOV	Low	[11]	276	190,665	320,188	316,516	292,119
	High	[12]	393	271,634	456,162	450,930	416,173
Percentage Decline Relative to NHTSA Baseline							
Fatalities Eliminated	Low and High	[13]	-20.2%	-38.0%	-51.8%	-62.5%	-69.3%
MAIS 1-5 Injuries	Low and High	[14]	-23.0%	-42.4%	-57.0%	-67.8%	-74.5%
PDOV	Low and High	[15]	-10.2%	-20.2%	-29.2%	-37.1%	-42.8%

Notes and Sources:

[1] - [6]: See V2V Technology Report, Table XII-7, p. 297.

[7] - [8]: Applies annualized trend in fatalities of -2.48 percent. NHTSA 2010 Data Summary, Exhibit 2, p. 4.

[9] - [10]: Applies annualized trend in injuries of -2.86 percent. NHTSA 2010 Data Summary, Exhibit 2, p. 4.

[11] - [12]: Applies annualized trend in PDOVs of -1.18 percent. NHTSA 2010 Data Summary, Exhibit 2, p. 4.

[13] = ([8] - [2]) / [2].

[14] = ([10] - [4]) / [4].

[15] = ([12] - [6]) / [6].

B. MONETIZING BENEFITS: VSL AND THE VALUE OF MAIS INJURIES AND PDOV

The benefits from a mandate must be monetized and discounted to present value in a meaningful CBA. The DOT periodically publishes precise guidelines on how to value a reduction of fatalities and injuries. In its most recent update, the DOT suggested “a VSL of \$9.1 million in current dollars for analyses using a base year of 2012” based on “[e]mpirical studies published in recent

years.”¹²¹ The DOT further required “that an income elasticity of 1.0 should be used to project VSL to future years” along with “an expected 1.07 percent annual growth rate in median real wages over the next 30 years (2013-2043).”¹²² Accordingly, we construct the monetary value of the fatalities eliminated in a given year by multiplying this number by the VSL for the year, assuming a growth rate of 1.07 percent in the VSL. The DOT further requires that “[a]lternative high and low benefit estimates should be prepared”¹²³ using “alternative VSLs of \$5.2 million and \$12.9 million.”¹²⁴ Results for low and high VSLs are presented in Appendix A.

The DOT uses a standardized method to construct the values of non-fatal injuries scaled in proportion to VSL. Specifically, the DOT provides coefficients for each AIS injury class to be applied to VSL to construct a value corresponding to a fraction of a fatality.¹²⁵ In its most recent update, the DOT suggested coefficients of, respectively, 0.003, 0.047, 0.105, 0.266 and 0.593 for AIS injuries 1 through 5.¹²⁶ The NHTSA benefit analysis, however, does not provide information about the breakdown of injuries avoided across the different AIS injury classes. To overcome this limitation and illustrate how to correct this deficiency, in our analysis we construct a preliminary measure of the value of injuries avoided in a given year by multiplying this number by the VSL times the coefficient for AIS 2 injuries, 0.047. While we recognize that an accurate analysis requires an accounting for the distribution of injuries by class, we believe that using the coefficient for AIS type 2 injuries is appropriate as a preliminary approach. In fact, the number of injuries is decreasing in the severity of the injury—implying the median injury is lower than an AIS type 3 injury—and the crash avoidance benefits of DSRC are lower as the speed of cars increases.¹²⁷ Since the more severe injuries are more likely at higher speeds, the benefits of

¹²¹ DOT VSL Memo, Cover page. Note that according to the guidelines, “[p]revention of an expected fatality is assigned a single, nationwide value in each year, regardless of the age, income, or other distinct characteristics of the affected population, the mode of travel, or the nature of the risk.” DOT VSL Memo, p. 3.

¹²² DOT VSL Memo, Cover page.

¹²³ DOT VSL Memo, p. 3.

¹²⁴ DOT VSL Memo, p. 11.

¹²⁵ The measures reflect “the quality-adjusted percentage of remaining life lost for median utility weights.” See DOT VSL Memo, p. 9.

¹²⁶ Note that these percentages vary depending on the rate at which disability is discounted over a victim’s lifespan. The numbers above are those chosen by the DOT “corresponding to an intermediate rate of 4 percent for use in all analyses.” DOT VSL Memo, p. 9.

¹²⁷ The statement can be inferred by considering the distribution of crashes by vehicle approaching speeds. See V2V Technology Report, Tables XII-8, 11, and 14, pp. 278, 281-282.

DSRC are likely to be skewed to the less severe AIS injury types. Therefore, using the AIS type 2 injury as representative is likely a conservative assumption. We further construct the value of PDOV by multiplying the number of PDOV avoided by the average auto liability claim for property damage in 2013, \$3,231.¹²⁸

C. OPPORTUNITY COST OF SPECTRUM USE

Based on the analysis in Section V, above, we use an opportunity cost of spectrum of \$15 billion per year, with sensitivities of \$10 billion and \$20 billion, to represent the social value lost from not sharing the 5.9 MHz allocation with Wi-Fi. Similarly to our assumption for the VSL, we grow the opportunity cost of spectrum assuming a growth rate of 1.07 percent—the expected growth rate in median real wages over the next 30 years. As noted above, however, the opportunity cost of spectrum may well grow at a rate faster than general economic activity as the use of mobile devices and total internet traffic is expected to substantially increase in the next few years suggesting this growth rate is likely conservative.¹²⁹

D. MISCOMMUNICATION PROBABILITY AND REPLACEMENT COSTS OF V2V DEVICES

The NHTSA’s benefit analysis improperly assumes that two vehicles equipped with a V2V DSRC device communicate with each other with 100 percent probability despite recognizing a need for a revocation list and acknowledging that urban canyons and heavy foliage can impact DSRC and GPS communications.¹³⁰ Furthermore, the cost analysis does not consider the replacement costs for broken or defective devices (or the costs associated with software updates necessary to keep the devices current). Both assumptions can result in a substantial overstatement of the net benefit.

¹²⁸ “Cost of Auto Crashes & Statistics,” RMIIA, available at http://www.rmiia.org/auto/traffic_safety/Cost_of_crashes.asp (accessed September 23, 2015).

¹²⁹ See “VNI Forecast Highlights,” Cisco Systems, available at http://www.cisco.com/web/solutions/sp/vni/vni_forecast_highlights/index.html (accessed September 23, 2015). See also footnote 114.

¹³⁰ V2V Technology Report, p. 26. Note that DSRC relies on a GPS antenna for vehicle positioning. Extensive research has highlighted the presence of substantial challenges for the efficacy of DSRC for safety warnings. For example, according to a recent study the maximum effective range for V2V warnings is 50 meters—well below the goal of 300 meters. Paul Alexander, David Haley, and Alex Grant, “Cooperative Intelligent Transportation Systems: 5.9-GHz Field Trials”, Proceedings of the IEEE (invited paper), 2010, p. 1227.

In our analysis of benefits we incorporate the possibility of failure or miscommunication among vehicles by multiplying the expected number of avoided fatalities, injuries and PDOVs by a miscommunication probability. While we do not possess the necessary information to appropriately calibrate such probability, to illustrate we provide initial estimates using a small miscommunication probability of 1 percent. Should the actual miscommunication rate be higher or lower, the adjustment would similarly be higher or lower.

The cost of broken or defective devices is incorporated in our analysis by assuming that a given percentage of V2V devices in circulation are replaced every year at the cost of a retrofit device. The number of devices in circulation is derived considering both the cumulative number of vehicles with a device installed and the scrappage rate for vehicles. The yearly scrappage rate for vehicles was derived by first projecting the population of vehicles through 2058 assuming a growth rate of 1 percent,¹³¹ and then backing out the number of vehicles scrapped in any given year using the NHTSA projections on new vehicles. We believe a rate of 2 percent to be a reasonable approximation of replaced devices.¹³² Sensitivity analysis conducted using different percentages did not significantly alter the result.

E. ADDITIONAL ASSUMPTIONS

Our CBA analysis requires a few additional assumptions and adjustments to the NHTSA's analysis to construct initial measures of the net benefit of a mandate.

The V2V Technology Report provides the yearly breakdown of devices installed on new vehicles under the three implementation scenarios and the number of aftermarket devices installed under scenario 1 between 2022 and 2026.¹³³ The report, however, does not explain what learning curve is being utilized, nor does it illustrate the vehicle equipment costs on a yearly basis. In our analysis we adopt a 92% learning curve—i.e. every time the aggregate production of devices is

¹³¹ Note that between 2003 and 2012, passenger vehicles grew by 13.4%, or at an annualized rate of 1.41. In more recent years, however, the growth rate has been substantially lower also due to the economic crisis. See, "Traffic Safety Facts 2012," U.S. Department of Transportation, National Highway Traffic Safety Administration, September 2014, p. 3.

¹³² Assuming a geometric decay of devices, a 2 percent rate is consistent with an expected life of 50 years, significantly more than the expected life of passenger vehicles.

¹³³ V2V Technology Report, pp. 230-231 and Table XI-13, p. 232.

doubled the average cost decreases by 8 percent—assuming that the estimated cost for 2020 holds for the first 5.96 million units.¹³⁴

We measure the cost of aftermarket devices by assuming that the same learning curve applies to aftermarket devices. These aftermarket devices include vehicle awareness devices (“VADs”) and after-market retrofit and self-contained devices (“ASDs”). Consistent with the NHTSA’s analysis, “ASD and VAD are assumed to have an equal penetration rate each year” under scenario 1—although it is unclear whether the distinction between VADs and ASDs is considered by the NHTSA in its benefit calculations. The average cost of an aftermarket device for 2020 is set equal by the average between the cost of a VAD and the average between the cost of retrofit and self-contained devices.¹³⁵ The costs of replacing a device are assumed equal to the installation of a retrofit device.

The NHTSA estimates the average expected increase in lifetime fuel costs for both light trucks and passenger cars, for model year 2020 and 2025. However, the agency does not report the fraction of passenger vehicles that are light trucks and only reports the incremental cost of fuel at the individual vehicle level. Furthermore, the agency does not indicate whether and how the fuel economy impact was applied to vehicles installing an aftermarket device. To construct the annual incremental costs of fuel we assume that the percentage of V2V devices installed on light trucks equals the percentage of light trucks in the existing population of vehicles. We also account for the fact that the incremental fuel costs due to aftermarket devices installed on used cars will be lower in proportion to the age of the vehicle on which they are installed.¹³⁶

¹³⁴ Note that the V2V Technology Report states that “V2V equipment production begins in 2020 with a price of \$329, the costs can range from \$249 to \$273 in 2022, and \$185 to \$199 in 2058” (p. 233) – the lower costs being associated to scenario 1. Given the aggregate production of devices over the years, a decrease from \$329 to \$185 is explained by a 92% learning curve if the estimated cost for 2020 holds for the first 5.96 million units. This is the number of devices installed in 2020 on new cars under scenarios 1 and 2. The report also states that, for aftermarket devices, “installation costs (which are just labor) will not be affected by the learning curve” (p. 229). In our analysis we apply the learning curve to the entire cost of aftermarket devices. This assumption lowers costs more quickly, conservatively pushing up net benefits.

¹³⁵ Note that the V2V technology report does not indicate the proportion of retrofit and self-contained devices under scenario 1.

¹³⁶ Under Scenario 1, aftermarket devices are installed in 2022 through 2026 on model-year 2015-2021 vehicles (V2V Technology Report, p. 261). To construct the fuel economy impact on these vehicles we assume that vehicles are 3 years old on average when the devices are installed and reduce the lifetime fuel economy impact by a fraction of equal to the percent of total vehicle miles traveled

Continued on next page

For system communication costs we use the yearly cost measures reported by the agency for the DSRC implementation scenario.¹³⁷ The NHTSA does not provide a yearly breakdown of the SCMS cost, but states that a one-time fee of approximately \$3.14 incorporated into the purchase price of a new vehicle could support the SCMS for all three scenarios.¹³⁸ Accordingly we construct yearly SMCS costs by multiplying this one-time fee by the number of devices installed on new vehicles.

F. RESULTS

We measure the yearly benefits and costs under Scenario 1 in 2012 dollars and discount them to present value as of 2015 using discount rates of 3 and 7 percent in line with the OMB guidelines.¹³⁹ We first measure the yearly benefits and costs under the NHTSA's original assumptions, and then adjust the estimates to account for trends in fatalities and injuries, miscommunication probability, replacement cost of devices and opportunity cost of not sharing 5.9 GHz spectrum. As we discuss below, once we correct the NHTSA's assumptions, the net benefits of a V2V mandate are dramatically reduced and, under some parameter assumptions, become negative. Regardless of the set of assumptions used for the CBA, sharing the spectrum always creates significantly better outcomes.

As an illustration, Figure 2 below reports the net benefit of a mandate without spectrum sharing under NHTSA's high benefit estimates using different values for the opportunity cost of the spectrum. The net benefits are calculated both under the NHTSA's original assumptions and correcting these assumptions to account for trends in fatalities and crashes, replacement costs of devices, and miscommunication probability among vehicles. As illustrated in Figure 2, the benefit of a mandate under the NHTSA's assumptions overestimates the actual benefit of a mandate by between \$591 and \$757 billion depending on the value of the spectrum. At a spectrum valuation of \$20 billion per year, the NHTSA's proposed mandate actually results in net

Continued from previous page

during the first three years. Specifically, during their first three years from purchase cars and light trucks travel on average 27 and 25 percent, respectively, of their total lifetime vehicle miles (see "Vehicle Survivability and Travel Mileage Schedules," NHTSA, January 2006, Tables 9c, p. 30, and Table 10c, p. 33).

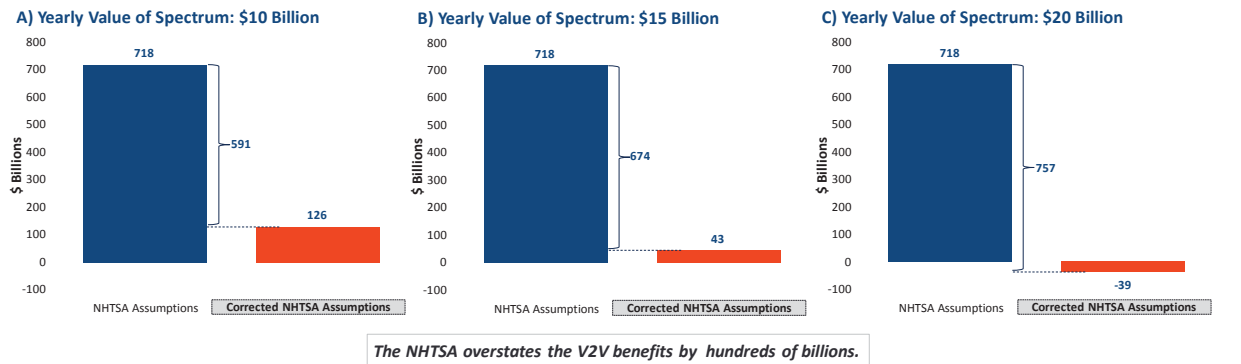
¹³⁷ V2V Technology Report, Table XI-24, p. 250.

¹³⁸ See discussion in footnote 38, above, regarding this cost.

¹³⁹ As discussed in Section III above, OMB Circular A-4 provides for use of 3 and 7 percent discount rates. See OMB Circular A-4, p. 33.

negative welfare impact of \$39 billion, illustrating that the opportunity cost of going forward with a V2V mandate in a manner that prevents spectrum sharing would not maximize social welfare.

Figure 2: Net Benefit of V2V Mandate without Spectrum Sharing

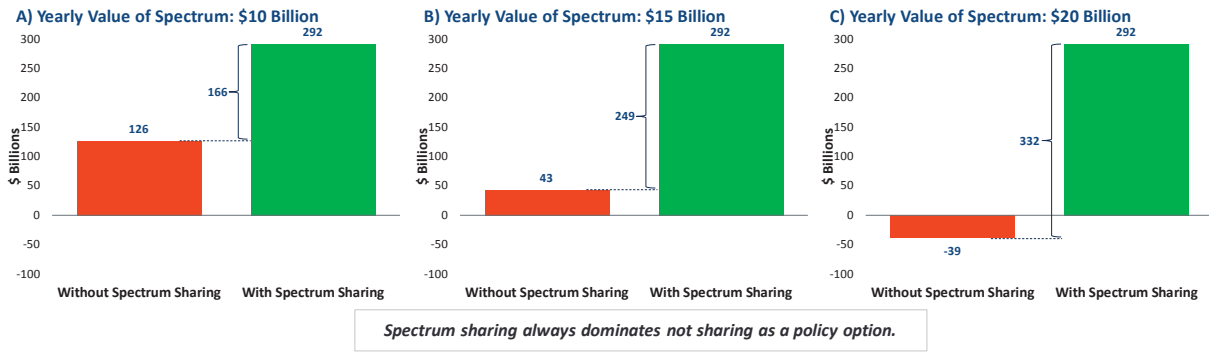


Notes:

Net Benefits are calculated using the NHTSA high benefit estimates, including trends for fatalities, injuries, and PDOV, using a 2 percent replacement rate for V2V devices, a 7% discount rate, and 1 percent miscommunication probability.

For illustrative purposes, in Figure 3 we compare the net benefit of a mandate with and without spectrum sharing using the NHTSA high benefit estimates and a 7% discount rate. As Figure 3 clearly indicates, spectrum sharing in the U-NII 4 band promotes overall social welfare. Sharing a portion of the spectrum in fact clearly dominates the policy alternative of not sharing, increasing the net benefit of a mandate by between \$166 and \$332 billion depending on the value of the spectrum.

Figure 3: Net Benefit of V2V Mandate under Alternative Values of the Spectrum



Notes:

Net Benefits are calculated using the NHTSA high benefit estimates, including trends for fatalities, injuries, and PDOV, using a 2 percent replacement rate for V2V devices, a 7% discount rate, and 1 percent miscommunication probability.

Table 3 below summarizes our results and compares the net benefit of the technology mandate under alternative assumptions. Specifically, the welfare impact of a mandate is calculated using discount rates of 3 and 7 percent, and an opportunity cost of spectrum of \$10, \$15, and \$20 billion. Columns 1 and 2 of the table report the low and high welfare estimates for the two discount rates under the NHTSA’s assumptions. Columns 3-8 report high and low welfare estimates from the corrected analysis both with and without spectrum sharing. As Table 3 indicates, under the NHTSA’s assumptions, the net benefits of a mandate range between \$495 billion of the low estimate at a 7 percent discount rate and \$1,970 billion of the high estimate at a 3 percent discount rate. However, once we correct the NHTSA’s assumptions, the net benefits of a mandate without spectrum sharing are dramatically reduced and, under some parameter assumptions, become negative.

Table 3: Net Benefit of V2V Mandate

	NHSTA Assumptions		Alternative Assumptions					
	1	2	3	4	5	6	7	8
Assumptions								
Trend in Fatalities	0.0%	0.0%	-2.5%	-2.5%	-2.5%	-2.5%	-2.5%	-2.5%
Trend in Injuries	0.0%	0.0%	-2.9%	-2.9%	-2.9%	-2.9%	-2.9%	-2.9%
Trend in PDOV	0.0%	0.0%	-1.2%	-1.2%	-1.2%	-1.2%	-1.2%	-1.2%
Replacement rate for V2V devices	0.0%	0.0%	2%	2%	2%	2%	2%	2%
Misscommunication probability	0.0%	0.0%	1%	1%	1%	1%	1%	1%
Discount Rate	3%	7%	3%	3%	3%	7%	7%	7%
Yearly Cost of Spectrum (\$ billion)	0	0	10	15	20	10	15	20
<i>PV of Cost of Spectrum (\$ billion)</i>	<i>0.00</i>	<i>0.00</i>	302	452	603	166	249	332
PV of V2V Mandate (\$ billion)								
Without Spectrum Sharing								
Low Estimate	1,369	495	192	42	-109	25	-58	-140
High Estimate	1,970	718	442	292	141	126	43	-39
With Spectrum Sharing								
Low Estimate			494	494	494	191	191	191
High Estimate			744	744	744	292	292	292
Difference (=PV of Cost of Spectrum)								
Low and High Estimates			302	452	603	166	249	332

Notes:

PV are calculated using a 2 percent replacement rate for V2V devices, a 1 percent miscommunication probability, and the cost of spectrum grown at 1.07% to reflect real income growth.

The net benefits of a V2V DSRC mandate without spectrum sharing range between a net loss of \$140 billion under the NHTSA low estimate and a 7 percent discount rate, and a benefit of \$442 billion under the NHTSA high estimate and a 3 percent discount rate. Conversely, sharing a portion of the spectrum substantially increases the net benefit of a mandate over not sharing. The net benefits of a V2V DSRC mandate allowing for shared use of the lower portion of the 5.9 GHz band always produce large, positive benefits ranging between \$191 and \$744 billion. Most importantly, regardless of the parameter assumptions used, shared use of the lower portion of the 5.9 GHz band would both achieve the full safety benefits of V2V communications and maximize the value of the spectrum, producing a surplus ranging between \$166 and \$603 billion. Results for low and high VSLs are presented in Appendix A.

Appendix A: CBA Results Using Low and High VSLs

Table A1: Net Benefit of V2V Mandate for Low and High Values of VSL

a) Low Value of VSL								
	NHTSA Assumptions		Alternative Assumptions					
	1	2	3	4	5	6	7	8
Assumptions								
Trend in Fatalities	0.0%	0.0%	-2.5%	-2.5%	-2.5%	-2.5%	-2.5%	-2.5%
Trend in Injuries	0.0%	0.0%	-2.9%	-2.9%	-2.9%	-2.9%	-2.9%	-2.9%
Trend in PDOV	0.0%	0.0%	-1.2%	-1.2%	-1.2%	-1.2%	-1.2%	-1.2%
Replacement rate for V2V devices	0.0%	0.0%	2%	2%	2%	2%	2%	2%
Misscommunication probability	0.0%	0.0%	1%	1%	1%	1%	1%	1%
Discount Rate	3%	7%	3%	3%	3%	7%	7%	7%
Yearly Cost of Spectrum (\$ billion)	0	0	10	15	20	10	15	20
<i>PV of Cost of Spectrum (\$ billion)</i>	<i>0.00</i>	<i>0.00</i>	302	452	603	166	249	332
PV of V2V Mandate (\$ billion)								
Without Spectrum Sharing								
Low Estimate	751	266	-63	-213	-364	-78	-161	-244
High Estimate	1,098	395	83	-68	-219	-19	-102	-185
With Spectrum Sharing								
Low Estimate			239	239	239	88	88	88
High Estimate			384	384	384	147	147	147
Difference (=PV of Cost of Spectrum)								
Low and High Estimates			302	452	603	166	249	332
b) High Value of VSL								
	NHTSA Assumptions		Alternative Assumptions					
	1	2	3	4	5	6	7	8
Assumptions								
Trend in Fatalities	0.0%	0.0%	-2.5%	-2.5%	-2.5%	-2.5%	-2.5%	-2.5%
Trend in Injuries	0.0%	0.0%	-2.9%	-2.9%	-2.9%	-2.9%	-2.9%	-2.9%
Trend in PDOV	0.0%	0.0%	-1.2%	-1.2%	-1.2%	-1.2%	-1.2%	-1.2%
Replacement rate for V2V devices	0.0%	0.0%	2%	2%	2%	2%	2%	2%
Misscommunication probability	0.0%	0.0%	1%	1%	1%	1%	1%	1%
Discount Rate	3%	7%	3%	3%	3%	7%	7%	7%
Yearly Cost of Spectrum (\$ billion)	0	0	10	15	20	10	15	20
<i>PV of Cost of Spectrum (\$ million)</i>	<i>0.00</i>	<i>0.00</i>	302	452	603	166	249	332
PV of V2V Mandate (\$ billion)								
Without Spectrum Sharing								
Low Estimate	1,972	718	441	290	139	126	43	-40
High Estimate	2,820	1,033	793	642	492	268	185	102
With Spectrum Sharing								
Low Estimate			742	742	742	292	292	292
High Estimate			1,095	1,095	1,095	434	434	434
Difference (=PV of Cost of Spectrum)								
Low and High Estimates			302	452	603	166	249	332

Notes:

PV are calculated using a 2 percent replacement rate for V2V devices, a 1 percent miscommunication probability, and the cost of spectrum grown at 1.07% to reflect real income growth.

Appendix B: Congestion in the 5 GHz band

As introduced in Section V, a critical component of value that could be generated by allowing shared use of the lower portion of the 5.9 GHz or U-NII 4 band is the potential congestion relief for residential Wi-Fi that would result from added Wi-Fi network capacity.¹⁴⁰

Although a large number of engineering studies have analyzed the performance of wireless local area networks, and despite the fact that many authors have suggested that widespread unlicensed network congestion is likely to occur, especially in public places and dense urban environments, no study has directly assessed whether congestion is actually a problem today and/or will be in the relatively near future, especially in the 5 GHz band.¹⁴¹ The main problem with modeling congestion is that, while assessing the capacity of a single transmission technology in a single Access Point (“AP”), single client world is straightforward, the actual capacity of a local area network crucially depends both on the different transmission technologies employed and how heavily they are used. Understanding the likely occurrence and impact of congestion thus requires modeling complex interactions or adopting simplifying assumptions.

In what follows, we address the problem by studying the capacity of a local area network in terms of the maximum number of simultaneous applications that a wireless network can support before congestion occurs. Instead of explicitly modeling potential interference and additional overhead caused from multiple clients sharing the same channel we incorporate these considerations through the network efficiency metric.¹⁴² Using such approach, we compute the

¹⁴⁰ As noted in the text, we believe that the value generated by additional spectrum for Wi-Fi in the U-NII 4 band can be decomposed into three main components. First, there is the increased value of existing uses generated by reduced congestion and improved quality. Second, there is the value generated by the new uses that would emerge because of a higher capacity. Third, there is the value generated by spillover effects on innovation and technology adoption coming from new and improved, potential and existing uses. Congestion relief for residential Wi-Fi falls in the first of the three components of value, but only constitutes part of the total value generated.

¹⁴¹ Partial exceptions include a 2005 work by Jardoash et al., in which the authors studied performance degradation from congestion in 802.11b wireless networks, but did not investigate how wide-spread congestion was in practice, and a 2013 study by Rob Alderfer, in which the author investigates congestion in the 2.4 GHz band, but not the 5 GHz band. See Amit P. Jardoash, Kevin C. Almeroth Elizabeth M. Belding-Royer, “Understanding Congestion in IEEE 802.11b Wireless Networks, 2005; and Rob Alderfer, “Wi-Fi Spectrum: Exhaust Looms,” 2013.

¹⁴² Network efficiency here denotes the actual throughput divided by the maximum theoretical throughput of the Wi-Fi network using a given data transmission technology.

potential congestion relief for residential Wi-Fi from shared use of the U-NII 4 band by first estimating the capacity of the network at 5 GHz—the only band where the 802.11ac Wi-Fi standard operates—with and without sharing of the U-NII 4 band, and then using tract-level census data to determine the areas that are likely to be congested without sharing, but not congested with sharing. These are the areas that will receive the greatest benefits from sharing the U-NII 4 band.

Our results suggest that congestion in residential Wi-Fi use is likely to occur during peak usage times in densely populated areas even if all devices were using the latest IEEE 802.11ac standard in the near future. Notably, as consumer demand continues to increase, congestion will remain high even if the U-NII 4 band becomes available, demonstrating the need for increased unlicensed spectrum resources beyond this one band. However, sharing the lower portion of the 5.9 GHz band would relieve a non-trivial portion of the areas from congestion.

B1. 5 GHz Wi-Fi: CAPACITY AND MAXIMUM NUMBER OF SIMULTANEOUS APPLICATIONS

A real world Wi-Fi network will have many different types of applications with different levels of demand for network capacity. Modeling such an environment can quickly become immensely complicated. Such complication, however, is unlikely to enhance any analytic results. Consequently, we model a simpler world with the expectation that any errors relative to actual use patterns will be both positive and negative and largely offsetting. Therefore, we measure the capacity of the network as the maximum number of simultaneous HD Video, HD Radio and VoIP applications using the network before congestion occurs. The analysis is summarized in Table B1 below.

We assume that all devices use the 802.11ac standard.¹⁴³ We first retrieve the maximum theoretical capacity of a single channel using different transmission technologies from the

¹⁴³ Note that this is a very conservative assumption in that both the capacity and efficiency of a network crucially depend on the transmission technology. Assuming that all devices use the 802.11ac standard at high coding rates and multiple spatial streams will substantially overestimate the actual capacity of a network that must share frequencies with other transmission technologies and the increasing number of non-Wi-Fi uses.

802.11ac amendment to the Wi-Fi standard.¹⁴⁴ The throughput capacity of a channel for each transmission technology is computed assuming 15 percent network efficiency.¹⁴⁵ Without the U-NII 4 band, households would have access to two 80 MHz and one 20 MHz channel.¹⁴⁶ With the U-NII 4 band, households would have access to three 80 MHz channels.¹⁴⁷ For each transmission technology we sum across the available channels to get the overall capacity of the network with and without the U-NII 4 band. In our framework, we do not directly or explicitly layer in potential interference and additional overhead caused from multiple clients sharing the same channel, although our efficiency measure assumes some amount of congestion. Overall, sharing the U-NII 4 band would increase the available channel bandwidth by 33.3 percent (from 180 MHz = 2 * 80 MHz plus 20 MHz to 240 MHz = 3 * 80 MHz) and increase the overall Wi-Fi network capacity by 35.5 percent.

To compute the maximum number of simultaneous applications that the network can support before congestion occurs we assume that HD Video would be streamed using devices allowing for two or three spatial streams at a 5/6 coding rate and 256-QAM modulation, while HD Radio and Voice would be using one stream and 64-QAM modulation.¹⁴⁸ Based on the actual network capacity of the transmission technology we estimate what percentage of the overall capacity is used by each of the three applications. We further assume that, on average, there would be two

¹⁴⁴ IEEE, Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, Amendment 4: Enhancements for Very High Throughput for Operation in Bands below 6 GHz, Tables 22-30 through 22-61, pp. 324-339.

¹⁴⁵ Between packet overhead and the protocols that allow for shared use of the airwaves, the effective efficiency is quite low. Our choice of 15% is a conservative guess of the average efficiency in heavily utilized channels. Timo Vanhatupa, for example, calculates that a single HD Video stream 10 Mbps using a QAM-64 modulation, 5/6 coding rate and 2 spatial streams would use 27.5 percent of a 40 MHz channel, resulting in an efficiency of 12 percent. The 12 percent is calculated by first calculating the theoretical end-user throughput if 100 percent of the channel was utilized ($10/0.275=36$ Mbps), and then dividing it by the maximum theoretical throughput in the channel (300 Mbps). Although efficiency can be higher in uncongested networks, it is the congested network environments that are relevant for the current analysis. Sensitivity analysis is performed below. See, Timo Vanhatupa, "Wi-Fi Capacity Analysis for 802.11ac and 802.11n: Theory & Practice," Ekahau, 2013, pp. 10-11.

¹⁴⁶ This includes one 80 MHz channel in U-NII 1 (from 5170-5250 MHz), one 80 MHz channel (from 5735-5815 MHz) and one 20 MHz channel (from 5815-5835 MHz) in U-NII 3.

¹⁴⁷ This includes one 80 MHz channel in U-NII 1 (from 5170-5250 MHz), two 80 MHz channel (from 5735-5815 MHz and from 5815-5895 MHz) in U-NII 3 and U-NII 4.

¹⁴⁸ These assumptions take into account what technologies are likely to be in use in the future. While the 802.11ac standard is capable of supporting up to 8 spatial streams, it is generally agreed that most consumer devices will be able to support a maximum of 3.

HD video streaming applications for every HD Radio or VoIP applications to get the percentage of capacity utilized by an average application. We find that the average application would consume 3.24 percent of the capacity without the U-NII 4 band and 2.39 percent with the U-NII 4 band. Expressed as the number of simultaneous applications supported, the 802.11ac Wi-Fi at 5 GHz could support up to 31 applications without and 42 applications with the U-NII 4 band.

**Table B1: 5 GHz Wi-Fi, Network Capacity
With and Without the U-NII 4 Band**

	Maximum Theoretical Channel Capacity			Network Capacity			
	20 MHz	80 MHz	80+80	Without Sharing the U-NII-4 Band		Sharing the U-NII-4 Band	
				Theoretical Max	Actual	Theoretical Max	Actual
Transmission Technology	[1] (Mbps)	[2] (Mbps)	[3] (Mbps)	[4] (Mbps)	[5] (Mbps)	[6] (Mbps)	[7] (Mbps)
1 Spatial Stream							
64-QAM	72	325	650	722	108	975	146
256-QAM	87	433	867	953	143	1300	195
2 Spatial Streams							
64-QAM	144	650	1300	1444	217	1950	293
256-QAM	173	867	1733	1907	286	2600	390
3 Spatial Streams							
64-QAM	217	975	1950	2167	325	2925	439
256-QAM	289	1300	2340	2889	433	3900	585
	Data Rate (Mbps)		Percent of Capacity Required		Maximum Number of Applications		
	[8]		No Sharing	Sharing	No Sharing	Sharing	
			[9]	[10]	[11]	[12]	
Application							
HD Video	20		5.56%	4.10%	18	24	
HD Audio	2		1.23%	0.91%	81	110	
Voice	1		0.62%	0.46%	162	219	
Average Application			3.24%	2.39%	31	42	
Capacity increase					-	35.47%	

Notes and Sources:

[1]-[3]: Maximum Theoretical Channel capacity, IEEE, Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, Amendment 4: Enhancements for Very High Throughput for Operation in Bands below 6 GHz, Tables 22-30 through 22-61.

[4]: = 2*[2] + [1].

[5]: = 15% * [4]. Efficiency is assumed at 15%.

[6]: = 3*[2].

[7]: = 15% * [6]. Efficiency is assumed at 15%.

[8]: Required Transmission Rates for HD Video, HD Radio and VoIP. Note that the bit rate for true HD Video can be as high as 40 Mbps for Blue Ray and 25 Mbps for HDV 1080i using MPEG2 compression. Similarly, the bit rate for true HD Audio can be as high as 9.6 Mbps for DVD Audio, and 1.4 Mbps for the standard audio CD. Today's over-the-top services, like Netflix (5 Mbps) and Spotify (0.3 Mbps), use lower bit rates due to lossy compression. Multimedia streaming also imposes additional client overhead.

[9]-[10]: = Required Transmission Rate / Network Capacity. As network capacity, we use the average between Actual Capacity at 2 and 3 spatial streams at 256-QAM for HD Video, between Actual capacity at 1 and 2 spatial streams at 64-QAM for HD Audio and Voice. The Percent of Capacity Required for the average application is a weighted average of the percentage required for HD Video (weighted 50%), HD Audio and Voice (weighted 25% each).

[11]: = 100% / [9].

[12]: = 100% / [10].

B2. MEASURING ADDED CAPACITY AND CONGESTION RELIEF

Using tract-level data from the 2010 U.S. Census, we look at population density to determine what areas are likely to be congested with and without sharing of the U-NII 4 band.¹⁴⁹ In our baseline analysis, we consider cells of 100 meters by 100 meters as the area that will use the 802.11ac channels. We further associate an average device with a person and therefore assume that in each cell there must be a number of people at least equal to the maximum number of applications supported for congestion to be likely to occur in a given census tract.¹⁵⁰ However, as demand for new and data-intensive applications is expected to increase, both the number of applications per household and the average throughput requirements per application are also likely to increase. According to Cisco, total IP traffic in North America will grow three-fold from 2014 to 2019, while the average traffic per user will grow by 172 percent. At the same time, Cisco predicts that residential Wi-Fi will increase from 33 percent of total IP traffic in 2014 to 49 percent in 2019.¹⁵¹ Such expected demand increases will in turn decrease the density threshold for congestion. We also consider the density thresholds assuming a 50 and 100 percent increase in demand per user.

As mentioned above, assuming network efficiency at 15 percent, the 802.11ac Wi-Fi at 5 GHz could support up to 31 and 42 simultaneous devices per cell with and without sharing in the U-NII 4 band. Since there are 100 such cells for every square kilometer (“km²”), based on our assumptions, without sharing of the U-NII 4 band congestion is estimated to occur in tracts with a population density of at least 3,100 people/km². But as demand is expected to grow, the threshold density for congestion would decrease to 2,067 people/km² with a 50 percent increase in demand and 1,550 people/km² with a 100 percent increase in demand. These density

¹⁴⁹ The U.S. is divided into 74,002 Census Tracts, with a populations density ranging between zero and 196,409 people/km² (in Chicago, IL), and a nationwide average density of 34.1 people/km². U.S. Census 2010 Population data.

¹⁵⁰ The simplifying assumption is likely to be conservative. In fact, density throughout a census tract is highly unlikely to be uniform, and the actual density around large buildings and building blocks is likely to be much higher than the tract’s average. As a result our analysis is conservative in that it will not capture congested areas within tracts in which population density is highly skewed around residential buildings. As a further sensitivity analysis we also consider smaller cells of 50 meters by 50 meters as the area for potential contention using the 802.11ac Wi-Fi standard.

¹⁵¹ “VNI Forecast Highlights,” Cisco Systems, available at http://www.cisco.com/web/solutions/sp/vni/vni_forecast_highlights/index.html (accessed September 3, 2015).

thresholds for congestion would increase, respectively, to 4,200, 2,800 and 2,100 people/km² if sharing of the U-NII 4 band is allowed.

To put these density thresholds in context, the current estimated density threshold that causes congestion of 3,100 people/km² describes neighborhoods¹⁵² in Fort Collins, Colorado, in the vicinity of Colorado State University¹⁵³ and in Salt Lake County, Utah.¹⁵⁴ Allowing sharing of the UNI-4 band would increase this threshold to 4,200 people/km². This would include areas such as downtown Syracuse, in the vicinity of Syracuse University.¹⁵⁵ Conversely, densely populated tracts in downtown Manhattan, San Francisco and other major cities often exceed population densities of 30,000 people/ km².¹⁵⁶

Results from our congestion analysis are summarized in Table B2 below. Even today, 45.1 million people, or 14.5 percent of the U.S. population, live in areas with a population density of at least 3,100 people/km². Wi-Fi congestion during peak usage times is likely to occur in these areas even with all devices using the most recent Wi-Fi standard in the near future. At the current level of demand, allowing shared use of the 5.9 GHz band would alleviate congestion for 14.8 million people living in areas with a population density between 3,100 and 4,200 people/km², or 4.8 percent of the U.S. population. In other words, shared use of the 5.9 GHz band would provide congestion relief to 32.9 percent of the congestion expected areas. However, as user demand is expected to increase, larger portions of the U.S. population would likely experience congestion every year. A 50 percent increase in user demand would increase the population living in congestion expected areas to 75.5 million, or 24.2 percent of the U.S. population, while doubling user demand would increase the population living in congestion expected areas to 101.6 million, or 32.6 percent of the U.S. population. A 50 percent increase in user demand would also increase the potential congestion relief from shared use of the U-NII 4 band to 31.3 million people, or 10.0 percent of the U.S. population, but as user demand grows even higher the expected congestion relief would decrease slightly. Notably, as consumer demand continues to increase, even the availability of U-NII 4 spectrum will fail to keep up with

¹⁵² Because we measure density at the Census tract level, illustrative densities of entire cities would be misleading because they would average in lower density areas with higher density areas.

¹⁵³ Census Tract 6, Larimer County, with a population density of 3,100 people/km².

¹⁵⁴ Census Tract 1003.08, Salt Lake County, with a population density of 3,101 people/km².

¹⁵⁵ Census Tract 43.01, Onondaga County, with a population density of 4,205 people/km².

¹⁵⁶ See, e.g., Census Tract 125.02, San Francisco County, California (62,355 people/km²) and Census Tract 207.01, New York County, New York (70,421 people/km²).

demand and expected congestion will remain high even if this band becomes available, demonstrating the need for increased unlicensed spectrum resources beyond this one band.

Table B2: 5 GHz Wi-Fi, Congestion With and Without the U-NII 4 band

	Without Sharing the U-NII-4 Band			Sharing the U-NII-4 Band			Congestion Relief		
	Density	Population		Density	Population		Population		% Reduction
	Threshold	('000)	(%)	Threshold	('000)	(%)	('000)	(%)	
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]
User Demand									
Current	>3,100	45,136	14.5%	>4,200	30,304	9.7%	14,831	4.8%	-32.9%
50 Percent Increase	>2,067	75,549	24.2%	>3,150	44,247	14.2%	31,303	10.0%	-41.4%
100 Percent Increase	>1,550	101,619	32.6%	>2,100	73,994	23.7%	27,625	8.9%	-27.2%
		[10]			[11]				
Supported Applications		31			42			-	

Notes:

[1], [4]: Tract-level population density threshold in people/km².

[2], [5]: Population, in thousands, living in tracts with a population density above the threshold.

[3], [6]: [2], [5] as a percentage of the U.S. population.

[7]: = [2] – [5].

[8]: [7] as a percentage of the U.S. population.

[9]: = ([6] – [3]) / [3].

[10], [11]: Maximum number of applications supported before congestion.

It is worth noting that although the most densely populated areas would continue to experience congestion even with the use of the additional frequencies, the level of congestion in these areas would be less, and the quality and reliability of service will increase. Even in the most congested areas there will be times when individual users do not experience congestion. Added Wi-Fi capacity would undoubtedly increase these times.

B3. SENSITIVITY

Our efficiency measure assumes contention for access to airwaves. But since greater or lesser contention can impact efficiency, we present sensitivity analyses of both the assumed efficiency levels and the area in which contention can occur.

In Table B3 below we summarize how results for the current level of demand vary depending on the value of the efficiency parameter utilized. As can be seen from the table, sharing of the lower portion of the 5.9 GHz band generally provides relief to 30 percent or more of the congested areas. Depending on the efficiency parameter utilized sharing would positively affect between two and seven percent of the U.S. population, at current Wi-Fi usage rates.

Table B3: Sensitivity Analysis on Congesting Relief, Efficiency Levels

	Without Sharing the U-NII-4 Band			Sharing the U-NII-4 Band			Congestion Relief		
	Supported Applications	Population ('000)	Population (%)	Supported Applications	Population ('000)	Population (%)	Population ('000)	Population (%)	% Reduction
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]
Efficiency									
10%	21	73,994	23.7%	28	51,620	16.5%	22,374	7.2%	-30.2%
15%	31	45,136	14.5%	42	30,304	9.7%	14,831	4.8%	-32.9%
20%	41	31,243	10.0%	56	21,718	7.0%	9,525	3.1%	-30.5%
25%	51	24,157	7.7%	70	16,811	5.4%	7,346	2.4%	-30.4%

Notes:

- [1], [4]: Maximum number of applications supported before congestion.
- [2], [5]: Population, in thousands, living in tracts with a population density above the threshold.
- [3], [6]: [2], [5] as a percentage of the U.S. population.
- [7]: = [2] – [5].
- [8]: [7] as a percentage of the U.S. population.
- [9]: = ([6] – [3]) / [3].
- [10], [11]: Maximum number of applications supported before congestion.

In Table B4 below we summarize how results vary if we consider cells of 50 meters by 50 meters as the area for potential contention using the 802.11ac Wi-Fi standard at current and future levels of demand. As can be seen from the table, if we restrict the contention area to a cell of 50 meters by 50 meters the percentage of U.S. population that would likely experience congestion is substantially reduced, but remains non trivial even under shared use of the U-NII 4 band. Shared use of the U-NII 4 band would still provide relief to 30 percent or more of the congested areas affecting between one and two percent of the U.S. population.

Table B4: Sensitivity Analysis on Contention Area

	Without Sharing the U-NII-4 Band			Sharing the U-NII-4 Band			Congestion Relief		
	Density Threshold	Population ('000)	Population (%)	Density Threshold	Population ('000)	Population (%)	Population ('000)	Population (%)	% Reduction
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]
A) Contention Area: 100 meters by 100 meters (Baseline)									
User Demand									
Current	>3,100	45,136	14.5%	>4,200	30,304	9.7%	14,831	4.8%	-32.9%
50 Percent Increase	>2,067	75,549	24.2%	>3,150	44,247	14.2%	31,303	10.0%	-41.4%
100 Percent Increase	>1,550	101,619	32.6%	>2,100	73,994	23.7%	27,625	8.9%	-27.2%
B) Contention Area: 50 meters by 50 meters									
User Demand									
Current	>12,400	8,300	2.7%	>16,800	5,904	1.9%	2,396	0.8%	-28.9%
50 Percent Increase	>8,268	13,725	4.4%	>12,600	8,129	2.6%	5,595	1.8%	-40.8%
100 Percent Increase	>6,200	19,292	6.2%	>8,400	13,494	4.3%	5,798	1.9%	-30.1%
Supported Applications		[10]			[11]				
		31			42				-

Notes:

[1], [4]: Tract-level population density threshold in people/km².

[2], [5]: Population, in thousands, living in tracts with a population density above the threshold.

[3], [6]: [2], [5] as a percentage of the U.S. population.

[7]: = [2] – [5].

[8]: [7] as a percentage of the U.S. population.

[9]: = ([6] – [3]) / [3].

[10], [11]: Maximum number of applications supported before congestion.

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