DSRC vs. Waiting for C-V2V: Lost Benefits and a Proposed Dual-Mode Solution

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Executive Summary

Although there is broad consensus that vehicle to vehicle (V2V) communications-based safety applications would have significant safety benefits, there has been considerable debate over the relative advantages and disadvantages of using Dedicated Short-Range Communications (DSRC) vs. Cellular Vehicle to all (C-V2X) as the radio media for vehicle to vehicle safety applications. One of the arguments for moving forward with DSRC-based deployment is that it is ready today, whereas C-V2X is not, and that delays mean fewer lives saved and lost benefits. To date, however, there has not been a quantitative estimate of these lost benefits.

The analysis in this paper first provides rough quantitative estimates of these lost benefits. The baseline scenario for the analysis assumes that a decision to wait for C-V2X would result in a delay of 5 years (3-year and 7-year delays are also analyzed). For the 5-year baseline scenario, the more rapid-deployment enabled by DSRC is estimated to save more than 3,800 lives.[1]

Table ES-1 Additional Lives Saved Through Earlier Deployment of V2V Safety Applications

	3 Year Delay		5 Year Delay		7 Year Delay	
	Low	High	Low	High	Low	High
Lives Saved	2,200	3,100	3,800	5,200	5,400	7,400

Lives saved are not the only benefits provided by V2V safety applications. There are also fewer injuries and less property damage. Table ES-2 shows the total additional monetized benefits gained through earlier deployment.

Table ES-2 Monetized Additional Benefits Through Earlier Deployment, in 2014 Dollars

	3 Year Delay		5 Year Delay		7 Year Delay	
	Low	High	Low	High	Low	High
3% Discount Rate	$85.6 B	$115 B	$145 B	$195 B	$203 B	$273 B
7% Discount Rate	$53.9 B	$72.2 B	$86.8 B	$116 B	$116 B	$155 B

IT IS BENEFICIAL TO MOVE FORWARD WITH A DSRC-BASED DEPLOYMENT, SAVING THOUSANDS OF ADDITIONAL LIVES, REGARDLESS OF WHETHER A LATER TRANSITION TO C-V2X PROVES ADVANTAGEOUS.

The results show that there are substantial benefits to be gained by moving forward with deployment. However, an argument for waiting is that C-V2X may prove to be superior in one or more ways, and therefore it would be advantageous to wait. To address this concern, this paper proposes a new approach, called "Dual-Mode Transition," where the nation moves forward with DSRC-based deployment, but transitions through a dual-mode deployment for several years before converting to purely C-V2X, should the latter prove superior in some way. The costs

[1] These numbers are based on the "Dual-Mode Transition" scenario described in the whitepaper. The additional benefits would be even greater if it is determined that there is no reason to transition to another technology, such as C-V2X.

and benefits of this approach are also estimated and compared with the costs and benefits of just waiting for C-V2X. The results show that *even with the additional costs of dual-mode systems, this "Dual-Mode Transition" approach with a transition period provides benefits from earlier deployment that significantly outweigh the additional costs*. Although further analysis is needed, such as refinement of the cost-benefit analysis, confirmation of the technical feasibility of the dual-mode approach, and further assessment of the impact of the increased in-vehicle costs, *this analysis provides quantitative data supporting moving forward with a DSRC-based deployment, regardless of whether C-V2X proves to offer advantages in the longer term. However, it is also important to realize that further delay in deploying V2V safety comes at a cost in terms of lost lives, more injuries, and increased property damage. Not making a decision is equivalent to making a decision to delay.*[2]

The total net benefits (benefits minus costs) for the proposed "Dual-Mode Transition" scenario are shown in Table ES-2.

Table ES-2 Total Net Benefits, in 2014 $, of the "Dual-Mode Transition" Scenario

	3 Year Delay		5 Year Delay		7 Year Delay	
	Low	High	Low	High	Low	High
3% Discount Rate	$539 B	$759 B	$535 B	$753 B	$534 B	$751 B
7% Discount Rate	$210 B	$302 B	$211 B	$302 B	$212 B	$311 B

Table ES-3 shows the incremental net benefits for the "Dual-Mode Transition" scenario vs. the "Wait for C-V2X" scenario. Again, the net benefits, considering the higher costs of dual-mode systems, are positive under all scenarios.

Table ES-3 Incremental Net Benefits, in 2014 $, of the "Dual-Mode Transition " Scenario vs. the "Wait for C-V2X" Scenario

	3 Year Delay		5 Year Delay		7 Year Delay	
	Low	High	Low	High	Low	High
3% Discount Rate	$66.0 B	$95.4 B	$124 B	$174 B	$181 B	$251 B
7% Discount Rate	$53.9 B	$61.7 B	$69.8 B	$99.0 B	$116 B	$136 B

The numbers used in this analysis are primarily drawn from NHTSA's Notice of Proposed Rulemaking and its preliminary impact analysis. (1), (2)

[2] This analysis starts from the premise that some form of V2V safety applications deployment is desirable, based on the analysis conducted by NHTSA and others. It analyzes several alternatives for deploying V2X safety applications. Debate on the merits of connected vehicle V2V safety applications is outside the scope of this white paper.

Introduction

There is an ongoing and intensifying debate between advocates of deploying Dedicated Short-Range Communications (DSRC) as the radio medium for vehicle to vehicle safety communications and those who advocate using a newly-emerging cellular technology, Cellular V2X (C-V2X) as the radio medium for such communications.[3] One of the factors involved is timing. DSRC (3) has been extensively tested, with equipment deployed in thousands of vehicles for test and evaluation purposes, and complete products are available for commercial use. One vehicle model, the 2017 Cadillac CTS (4), currently includes DSRC as standard equipment. On the other hand, standards for C-V2V communications were just completed in the fall of 2016, and a chip set that products can be built around has only recently been announced by Qualcomm (5).

It is generally accepted that DSRC technology is more mature and can be deployed more quickly than C-V2X, which would yield additional benefits. Therefore, if all other factors turn out to be equal, there would be no reason to consider C-V2X as an alternative. If, on the other hand, C-V2X turns out to have advantages that DSRC lacks, as claimed by its proponents, then it makes sense to consider either waiting for C-V2X to mature or rolling out DSRC in the near-term, with an eventual transition to C-V2X. The argument for moving forward with DSRC in the latter case is that there are near term safety benefits that could be achieved by prompt deployment of DSRC and these additional benefits will be lost if the transportation community decides not to deploy the new safety applications until C-V2X is fully tested and available in production-ready products. At the same time, if a transition is required, earlier deployment of DSRC would entail additional costs that must be considered.

Although there have been published technical arguments for and against each alternative, and there have been qualitative arguments for moving forward with DSRC, there has not been a quantitative look at the advantages and disadvantages of moving forward with DSRC even if C-V2X should prove to have some advantage in the longer term. The purpose of this white paper is to illuminate this aspect of the debate by providing an initial, rough quantitative estimate comparing the costs and benefits of moving forward with DSRC vs. waiting for C-V2X. More specifically, the paper examines the costs of delaying V2V safety deployment, both in lives lost and monetary costs. It then compares the costs and benefits of a new strategy, called "Dual-Mode Transition" that quickly deploys DSRC while maintaining the option to later transition to C-V2X, including a period of dual deployment of both technologies, with the strategy of delaying implementation of V2V safety applications while waiting for C-V2X to mature. The analysis described below shows that there are significant benefits of moving forward with DSRC-based deployment, even if C-V2X eventually is shown to be a better future strategy, and that these benefits exceed the costs, even if a dual-mode strategy must be maintained for a significant number of years. The analysis is a rough initial estimate based on many simplifying assumptions. Nevertheless, it provides quantitative estimates of the costs and benefits of this approach, indicating further consideration of this option is warranted.

[3] See, for example, Autonomous Driving Experts Weigh 5G Cellular Network Against Dedicated Short Range Communications, published in IEEE Spectrum. (8)

Background on DSRC and C-V2X

DSRC and C-V2X are communications technologies proposed to support essentially the same set of connected vehicle applications, including safety, mobility, and environmental applications based on vehicle to vehicle (V2V), vehicle to infrastructure (V2I), and vehicle to other (e.g., pedestrians) communications. V2X (Vehicle to Everything) is used as the acronym to refer all the above types of communications.

DSRC is a variant of Wi-Fi that has been optimized for mobile environments and direct communications between devices, without an intermediary access point. It is defined in the IEEE 802.11p (6) standard (802.11 is the family of Wi-Fi standards, and 'p' is the DSRC version).

C-V2X is based on cellular direct device to device communications standards (e.g., that don't require communications with a cellular base station) and has been optimized for vehicular use cases, specifically addressing high speeds (up to 250 kilometers per hour) and high density (thousands of nodes). The current standard for C-V2X (7) was completed in September 2016.

The technical merits of the two alternatives are the subject of ongoing debate,[4] and are beyond the scope of this white paper.

Following years of testing, NHTSA issued a Notice of Proposed Rulemaking (1) in December 2016 that reflected an intent to mandate DSRC deployment. Widespread DSRC deployment in new vehicles could begin within two years of the final rule being issued. Because C-V2X is newer, with testing currently underway, it cannot be deployed as quickly as DSRC. Waiting for C-V2X creates a cost (lost benefits) in terms of accidents that occur due to the absence of V2V safety applications in vehicles sold in the interim. As stated above, the purpose of this white paper is to provide a rough quantitative estimate of these lost benefits and to compare the costs and benefits of waiting for C-V2X with an approach that moves forward with DSRC deployment while eventually transitioning to C-V2X. It is hoped that this approach provides additional information to aid in decision-making.[5]

Outline of This White Paper

The next section of this white paper describes the approach for defining the options for implementing V2V safety applications, the assumptions that are made to conduct the analysis, and the sources used for the data used in the analysis.

The Benefits subsection of the Analysis section first examines the incremental benefits that are gained by rapid deployment (i.e., the benefits that will be lost if deployment is delayed). It also calculates the benefits of the proposed "Dual-Mode Transition" scenario and compares them with the benefits of waiting for C-V2X to mature. The Costs subsection then calculates the total costs for the "Dual-Mode Transition" scenario, as well as the incremental costs of this scenario versus waiting for C-V2X.

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[4] See, for example, IEEE802.11p ahead of LTE-V2V for Safety Applications and Accelerating C-V2X Commercialization for two different perspectives and analysis.

[5] This analysis starts from the premise that some form of V2V safety applications deployment is desirable, based on the analysis conducted by NHTSA and others. It analyzes several alternatives for deploying V2X safety applications. Debate on the merits of connected vehicle V2V safety applications is outside the scope of this white paper.

The Net Benefits section combines these results to calculate the net benefits, and the final section of the white paper presents the conclusions that can be drawn from the analysis.

Analysis Approach

The two sides in the debate each argue that their preferred technology is a better match for V2V safety applications, and therefore argue that their preferred technology should be deployed. Table 1 describes four possible scenarios, two of which are compared in this paper.

Table 1 Four Possible Deployment Options

Scenario	Description & Rationale	Analyzed in this Paper
DSRC Now and Forever	DSRC deployment proceeds as quickly as possible, and continues. C-V2X is not deployed. This approach makes sense if C-V2X turns out to offer no significant advantages.	No
Wait for C-V2X	DSRC is set aside and never widely deployed. Instead, C-V2X is deployed as soon as it is sufficiently mature. If C-V2X turns out to have distinct advantages over DSRC, then this scenario is worth considering, and is put forth by proponents of C-V2X.	Yes
Rapid Change-Over	DSRC deployment proceeds as quickly as possible, but deployment ceases as soon as C-V2X is sufficiently mature. This scenario does not make economic sense, as a quick analysis of the NHTSA cost and benefit data show the costs would greatly exceed the limited benefits.	No
Dual-Mode Transition	DSCR deployment proceeds as quickly as possible. Once C-V2X is sufficiently mature, dual technology solutions are deployed for a number of years so that benefits continue to accrue to earlier DSRC equipped vehicles, with an eventual transition to only C-V2X.	Yes

This analysis assumes that DSRC and C-V2X approaches provide essentially the same safety benefits for a given level of market penetration (although C-V2X might offer additional non-safety benefits). The base case for this analysis compares a scenario where DSRC is initially deployed to capture earlier benefits with a phased later transition to C-V2X (called "Dual-Mode Transition"),[6] with an alternative scenario of never deploying DSRC and instead waiting for C-V2X to mature (called "Wait for C-V2X").

V2V safety benefits are only realized when two equipped vehicles would otherwise crash and one of the safety applications warns the driver in time to either prevent or reduce the impact of the crash. Therefore, the more vehicles that are equipped, the more benefits result. The Dual-Mode Transition scenario assumes that once C-V2X technology is ready for deployment, both DSRC and C-V2X are deployed on vehicles for many years. This is because the wait for C-V2X is expected to be less than 10 years, and if new vehicles were only equipped with C-V2X once it is available, then the total safety

[6] Dual-mode operations should be technically feasible. Per Qualcomm, "C-V2X and 802.11p can co-exist by being placed on different channels in the ITS band." See Qualcomm's *Accelerating C-V2X Commercialization* (9) presentation slides. As will be discussed later in the paper, this does add costs and some complexity during the transition period.

benefits of DSRC-equipped vehicles would start low (due to low levels of equipage in the vehicle fleet, due to slow fleet turnover, plateau, and begin to decline as soon as C-V2X becomes available. Given the small initial market penetration achieved during the early years of deployment, the benefits for those DSRC-equipped vehicles would be very small and would certainly not be cost-justified.[7] That is why the "Rapid Change-Over" scenario in Table 1 cannot be justified from a cost-benefit standpoint and is not considered further in this paper.

One of the major uncertainties is the lag time between when DSRC could be widely deployed versus when C-V2X could. The base case assumption in this analysis is five years. Three-year and seven-year lags are also examined. This analysis assumes that the transition period during which vehicles are dual-equipped with both DSRC and C-V2X is 12 years. The simplifying assumption is made that by this time approximately all the safety benefits that would accrue to those vehicles equipped only with DSRC will have been realized, as by that time, vehicles equipped with only DSRC (which would be only 5 model years ranging from 12-17 years old) will be out of service, and those that remain in operation average fewer miles traveled per year than newer vehicles.

Both scenarios assume that C-V2X offers some unspecified, but significant, advantage over DSRC once both are mature. If this assumption is incorrect, then there is no reason to consider C-V2X deployment as an alternative to DSRC, and DSRC should be deployed as soon as feasible.

Almost all of the data used in this analysis is based on the data in NHTSA's NPRM for V2V communications (1) and the accompanying Preliminary Regulatory Impact Analysis, FMVSS No. 150, Vehicle-to-Vehicle Communication Technology for Light Vehicles. (2) The benefit numbers and values are taken from that analysis, and, as a result, are based on just two V2V safety applications, Intersection Movement Assist (IMA) and Left Turn Assist (LTA). The NPRM proposes that the effective date for manufacturers to begin implementing DSRC would be two model years after the final rule is adopted, with a three-year phase-in period: 50 percent of vehicles three years after final rule; 75 percent four years after final rule; and 100 percent five years after final rule. The NPRM takes the first year of deployment to be 2021. Given the current delay in moving from the NPRM to the final rule, it is no longer realistic to assume that deployment year 1 will occur in 2021, so this analysis is conducted using deployment years rather than specific calendar years.[8]

The proposed rule only requires transmission of basic safety information over DSRC; it does not require any actual safety applications. The NPRM assumes that market forces will lead automakers to deploy safety applications that use this data, but with a time lag from the deployment of DSRC equipment, as shown in Tables VII-24 and VII-25 from the NPRM. The tables below, showing DSRC and V2V safety apps deployment for NHTSA's proposed DSRC rule, are based on the tables from the NPRM, but substitute

[7] NHTSA's NPRM states "This analysis identified the first model year for which the safety benefits from requiring vehicles to be equipped with V2V communications over their lifetime in the fleet would outweigh the higher initial costs for manufacturing them. It showed that this would occur in model year 2024 to 2026 if the proposed rule first took effect in model year 2021." This means that *assuming future vehicles continue to be equipped with DSRC,* the total cost for the first 3-5 model years exceeds the benefits. If future vehicles no longer include DSRC, the benefits would be significantly less.

[8] Any change in deployment year will also cause minor changes in the costs and benefits for several reasons, including the number of years one must discount to get back to 2014 dollars and the estimated number of vehicles produced, sold, and scrappage all vary by year. The initial rough estimate in this white paper ignores these effects.

the first model year of deployment, rather than assuming this occurs in 2021 as was done in the NHTSA analysis.

Table 2 Technology Adoption Rates for New Vehicles (in Percent), based on Table VII-24 in (1)

	Deployment Model Year							
	1	2	3	4	5	6	7	8
% Equipped with DSRC	50	75	100	100	100	100	100	100
% Equipped with V2V Safety Applications	0	5	10	25	40	65	90	100

Table 3 V2V Technology Fleet Penetration projected by NHTSA, based on Table VII-25 in (1)

Year	Number of Vehicles with DSRC Radios (Million)	Percent of Vehicle Fleet with DSRC Radios	Number of Vehicles with Apps (Million)	Percent of Vehicle Fleet with Apps
1	8.1	3.3%	0.0	0.0%
5	68.13	27.4%	6.3	5.2%
10	144.3	55.8%	87.2	33.7%
15	208.4	77.6%	163.7	61.0%
20	253.0	90.8%	226.1	81.2%
25	276.6	96.2%	265.3	92.3%
30	291.3	98.6%	286.9	96.8%
35	300.6	99.7%	298.1	98.9%
40	305.2	100.0%	304.6	99.8%

Analysis

Benefits

Because we are assuming that the benefits provided are independent of the communications technology used, the incremental benefits gained under the Dual-Mode Transition scenario are simply the area under the benefits curve for DSRC minus the benefits of later deployment of C-V2X (which is simply the DSRC benefits curve slid further out in time), with one complication. Benefits from DSRC equipage peaks the final year of dual mode deployment and begins to decline as newer vehicles without DSRC join the fleet and older DSRC-equipped vehicles are scrapped, whereas if DSRC continued to be deployed, the benefits would continue to increase for a further time. The base case assumes that dual-mode vehicle deployment begins five years after DSRC deployment and dual-mode deployment ends 16 years later.[9] Therefore, the benefits from DSRC-only and dual-mode DSRC peaks and begins to decline in deployment year 20. NHTSA's analysis did not include estimates of the total vehicle fleet size, by year, for future years were not available in the published reports, although this information presumably exists

[9] There is nothing special about a 16-year transition period. It was selected as a period of sufficient length such that almost all DSRC-only vehicles would no longer be on the road. Follow-on analysis can examine the ideal number of years for dual-mode equipage to maximize the net benefits, considering whatever advantages, if any, the C-V2X offers.

in the unpublished details of NHTSA's analysis. Therefore, the percentage of the vehicle fleet that consists of new vehicles in 2015 was used as an estimate, and the result rounded up to be conservative and to account for the scrappage of the few remaining DSRC vehicles in the fleet (which would now be at least 16 years old). In 2015, there were approximately 242 million cars and light trucks/vans on the road. (2) NHTSA estimates that new car and light truck/van sales were 16.2 million in the same year. (2, table A-2) This means that new vehicles make up approximately seven percent of the vehicle fleet. Therefore, for purposes of this analysis, and to be conservative, we reduce the annual DSRC benefits by 10% of its peak value per year until it crosses the C-V2X benefits curve. Using this approach, the estimated number of lives saved by the "Dual-Mode Transition" scenario vs. the "Wait for C-V2X" scenario is the delta between the "Dual-Mode Transition" curve and the "Wait for C-V2X curve. This is because the "Dual-Mode Transition" scenario still captures all the benefits of the "Wait for C-V2X" scenario. The additional lives saved by the "Dual-Mode Transition" scenario compared with the "Wait for C-V2X" are depicted in Figure 1 Lives Saved by the "Dual-Mode Transition" Scenario. This delta is represented by the blue shaded area in the figure.

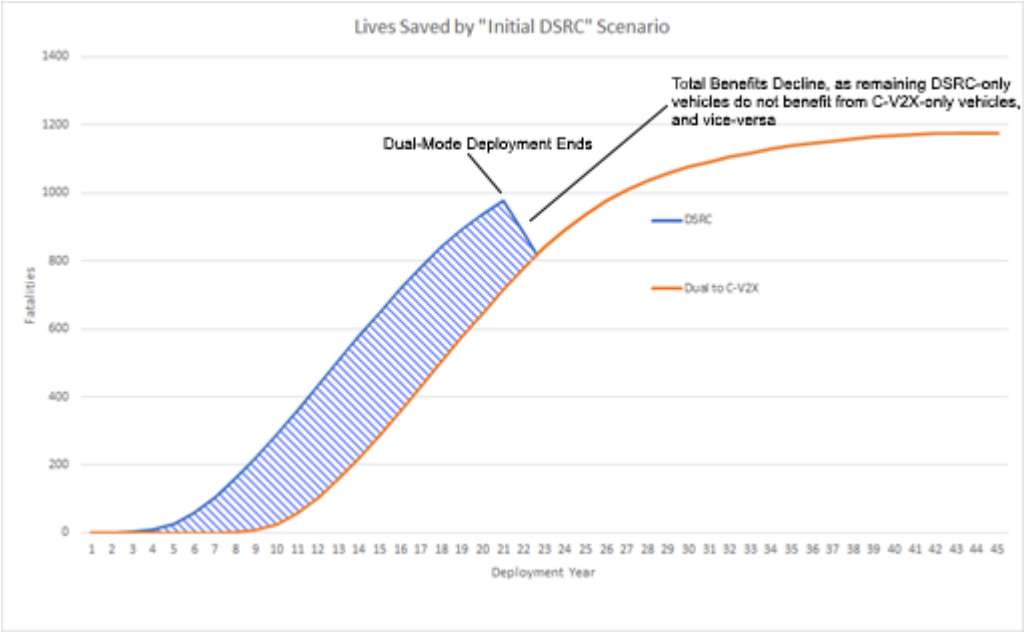

Figure 1 Lives Saved by the "Dual-Mode Transition" Scenario

The figures shown on the graph are an average of the "low" and "high" fatality benefits based on Tables V-17 (passenger car benefits) and V-18 (light trucks and vans benefits) in NHTSA's Preliminary Regulatory Impact Analysis (2), using the baseline five-year delay between when DSRC and C-V2X could be deployed, and assuming the same adoption rates for DSRC and V2V safety applications equipage. A 40-year period from initial deployment is used. The DSRC benefits are adjusted from the original NHTSA DSRC estimates to decrease at a rate of 10% per year beginning the year after dual-mode DSRC / C-V2X vehicle deployment ceases. The data tables are shown in Table A-1 in the appendix, and show that *the "Dual-Mode Transition" scenario will save between 3800 and 5,200 lives*.

If waiting for C-V2X requires only a three year wait (either because the technology is ready sooner, or because there continues to be a delay in the decision to move forward with DSCR), then there are still additional lives saved by the "Dual-Mode Transition" scenario. If, on the other hand, waiting for C-V2X

would require a seven-year delay, the additional lives saved rises even further. Table 4 shows both the baseline results as well as the alternative cases of a 3-year and 7-year delay. The baseline estimates are highlighted in the table. Note that *the "DSRC Now and Forever" scenario would, under these assumptions, save slightly more additional lives, since there would not be a drop off in benefits due to DSRC being phased out.* The data tables for this analysis is shown in Tables A-2 and A-3 in the Appendix. Note that the "DSRC Now and Forever" scenario would, under these assumptions, save slightly more additional lives, since there would not be a drop off in benefits because DSRC would not be phased out.

Table 4 Additional lives saved by the "Dual-Mode Transition" scenarios vs. "Waiting for C-V2X"

	3 Year Delay		5 Year Delay		7 Year Delay	
	Low	High	Low	High	Low	High
Lives Saved	2,200	3,100	**3,800**	**5,200**	5,400	7,400

The same approach is used to calculate the total difference in monetized benefits, including the benefits from reductions in fatalities, injuries and property damage. NHTSA applies discounting at two different rates (3% and 7%) and converts all values back to 2014 dollars (see Tables VIII-2 and VIII-3 in (2)), and the values used in this analysis are based on the values shown in those tables, and use the same assumptions. To calculate the benefits from C-V2X, the benefits values are shifted to later years, as was done for fatalities, and in addition, the benefits are discounted to account for the shift (the same discounting is used for shifted costs as well).

Using a 3% discount rate and the baseline 5-year delay to deploy C-V2X, the "Dual-Mode Transition" scenario provides between $145 billion and $195 billion in additional benefits when compared with the "Wait for C-V2X" scenario (because it captures all the benefits of the "Wait for C-V2X" scenario plus the additional benefits gained from earlier deployment using DSRC). Using a 7% discount rate, and the baseline 5-year delay to deploy C-V2X, the "Dual-Mode Transition scenario provides between $86.8 billion and $116 billion in additional benefits.

Table 5 shows these results, along with the results for the 3-year and 7-year alternate cases.

Figures 2 and 3 illustrate the additional benefits using the baseline 5-year delay and an average of the low and high values cited above. The monetized discounted benefits tail off and decrease in the out years because maximum benefit has been achieved and the discounted value is lower in the out years. Similarly, while the maximum annual benefit for DSRC and C-V2X approaches are identical in *undiscounted* dollars, the peak benefit for C-V2X is less in discounted dollars because the benefits occur later (the costs in discounted dollars are also lower due to this delay). As with the analysis of lives saved, *the "DSRC Now and Forever" scenario would, under these assumptions, provide even more benefits, because there would not be a drop off in benefits due to DSRC being phased out.*

The detailed data tables for a 3% discount rate are shown in Tables A-4, A-5, and A-6. The detailed data for a 7% discount rate are shown in Tables A-7, A-8, and A-9.

Table 5 Monetized Incremental Benefits of the "Dual-Mode Transition" Scenario vs. the "Wait for C-V2X" Scenario, in 2014 Dollars

	3 Year Delay		5 Year Delay		7 Year Delay	
	Low	High	Low	High	Low	High
3% Discount Rate	$85.6 B	$115 B	$145 B	$195 B	$203 B	$273 B
7% Discount Rate	$53.9 B	$72.2 B	$86.8 B	$116 B	$116 B	$155 B

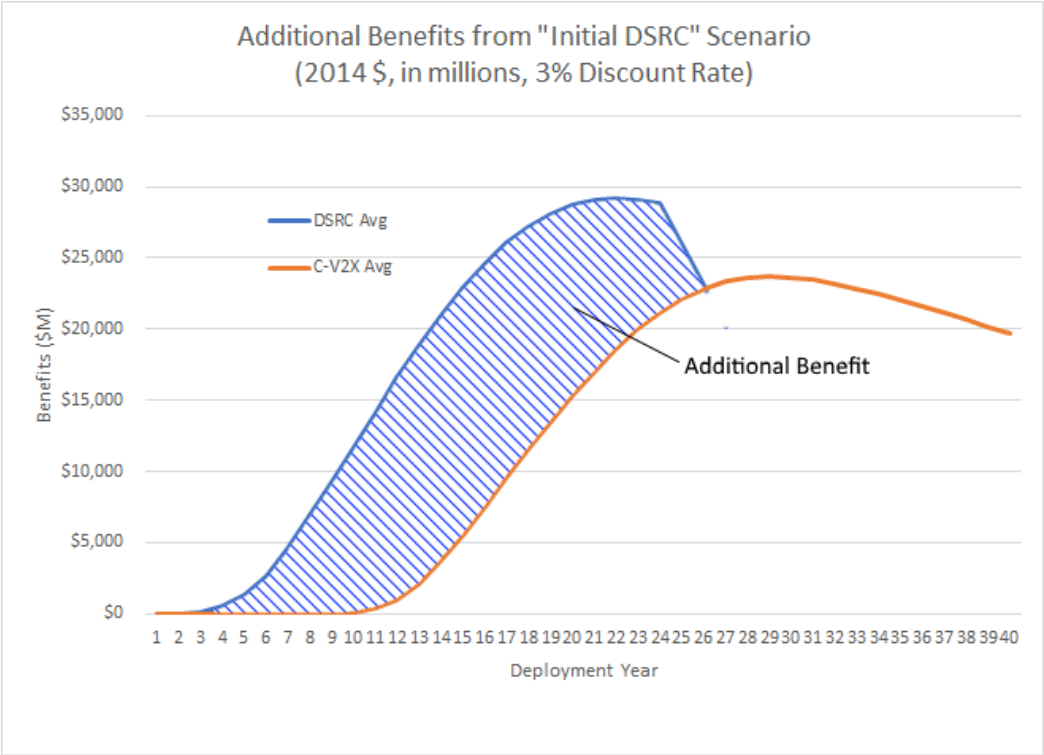

Figure 2 Additional Monetized Benefits of the "Dual-Mode Transition" Scenario vs. the "Wait for C-V2X" Scenario, in 2014 $ using a 3% Discount Rate

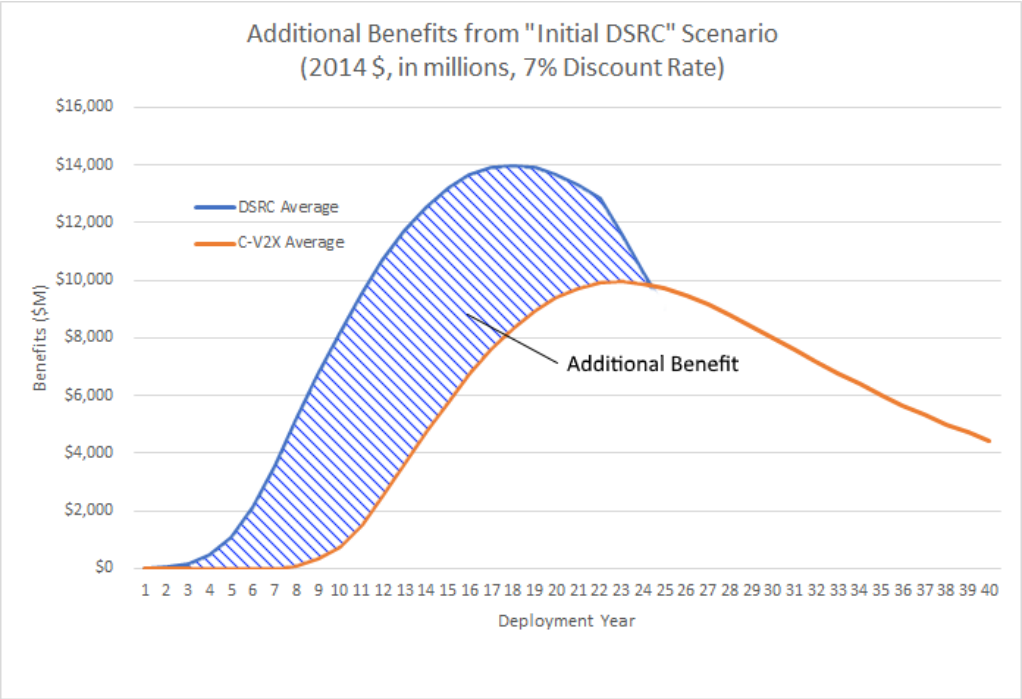

Figure 3 Additional Monetized Benefits of the "Dual-Mode Transition" Scenario vs. the "Wait for C-V2X" Scenario, in 2014 $ using a 7% Discount Rate

The *total* (not differential) annual benefits of the "Dual-Mode Transition" scenario are initially the benefits from DSRC deployment, because, at first, there is no C-V2X deployment. Once dual-mode deployment begins, the benefits initially remain the same as they would for just DSRC, because dual-mode vehicles would not prevent any more crashes than DSRC alone. When dual-mode deployment ends, the annual benefits will be the sum of the now-declining benefits from DSRC (as non-DSRC vehicles are rapidly introduced into the fleet and DSRC-only and dual-mode vehicles are scrapped) plus the benefits from dual-mode and C-V2X only vehicles. For simplicity, and to err on the conservative side, we ignore the small residual benefits that would still accrue to the remaining DSRC vehicles once the DSRC-only benefits drop below the value for dual-mode and C-V2X vehicles. The monetized benefits are based on the same raw data from the NHTSA report as were Tables A-4 through A-9. The results are shown in Table 6, including the benefits for the 3-year and 7-year alternate cases. The baseline (5-year delay) total benefits over a 40-year period, in 2014 dollars, range from $269 billion (low estimate with a 7% discount rate) to $853 billion (high estimate with a 3% discount rate).

Table 6 Total Monetized Benefits for the "Dual-Mode Transition" Scenario in 2014 $

	3 Year Delay		5 Year Delay		7 Year Delay	
	Low	High	Low	High	Low	High
3% Discount Rate	$640 B	$860 B	$635 B	$853 B	$633 B	$850 B
7% Discount Rate	$270 B	$362 B	$269 B	$360 B	$269 B	$368 B

Costs

The additional benefits do not, of course, come for free. There are additional costs associated with implementing a dual-mode solution, as shown in Table 7 and discussed below.

Table 7 Summary of Cost Elements and the Impact of the Dual-Mode Transition

Cost Element	Role During Dual-Mode Transition	Notes
DSRC Transmitter / Receiver	Continued use, no cost impact	No longer deployed after transition period ends
DSRC Antenna	Continued use, no cost impact	No longer deployed after transition period ends
Electronic Control Unit	Shared use, no cost impact	The same unit can be used for single or dual-mode operations
GPS	Shared, no impact	The same unit can be used for single or dual-mode operations
GPS Antenna	Shared, no impact	The same unit can be used for single or dual-mode operations
Wiring	Shared, no impact	The same unit can be used for single or dual-mode operations
Displays	Shared, no impact	The same unit can be used for single or dual-mode operations
Hardware Security Module	Shared, no impact	The same unit can be used for single or dual-mode operations
Two Safety Applications	Modified to accept inputs from two communications systems, estimated 20% cost increase	
C-V2X Radio	Additional item needed for dual-mode operations, added cost estimated to be the same as the total cost for a DSRC radio	Continues to be deployed after transition period ends.
Communications Costs	Shared, no impact	Assume use of NHTSA's "hybrid" approach, which does not require widespread deployment of RSU's
SCMS	Shared, no impact	Security and privacy requirements are independent of the communications medium used
Fuel Economy Impact	Very minor impact of weight of 2nd radio during transition	Very small delta for 2nd radio, ignored in this analysis

The total cost for DSRC deployment includes costs for the on-board equipment, communications infrastructure, the Security Credentials Management System (SCMS), and some miscellaneous costs. During the dual-mode transition period, there will be additional costs for a second radio on-board each vehicle, as well as for modifications to the applications software (to address receiving messages from other vehicles over multiple media, including potentially receiving identical messages from the same vehicle on each medium).

At the same time, much of the same infrastructure can be shared in the dual-mode approach. The NHTSA analysis considers two approaches for exchanging security information with vehicles. The first assumes a second DSRC radio and a large, dense nationwide deployment of DSRC Road Side Units (RSUs). The second approach assumes a mix of satellite, Wi-Fi, and cellular radio is used. In this analysis, we propose that the "Dual-Mode Transition" scenario uses the latter approach, because there is less justification for deploying a dense nationwide network of RSUs if its use it to be temporary. Thus the "low cost" single radio costs are used as the starting point (but see below for the added cost of a second C-V2X radio). Also, V2X applications have the same requirements for privacy and security regardless of communications media. Therefore, it is assumed that both DSRC and C-V2X systems could use this same security communications system as well as the same SCMS. The only additional costs for dual-mode transition systems are the in-vehicle hardware and software components. Therefore, we estimate that the *differential* cost of dual-mode vehicles is the cost of a C-V2X radio (for which we use NHTSA's estimated cost of a 2nd DSRC radio) plus an estimated 20% increase in software costs to account for the modifications needed to handle inputs from two communications media (however, this increased software cost is dwarfed by the cost of the second radio). If C-V2X radios turn out to be cheaper, this would increase the benefit/cost ratio. The other on-board equipment (GPS, user interface, etc.) would be shared, so there is no difference in cost for these items. As shown in Table A-9, this results in an increase of approximately 35% in the cost of the overall V2V system for each of the dual equipage years, although this varies slightly by year. The "Dual-Mode Transition" scenario would incur these additional costs beginning in the first year that C-V2X is deployed and continuing for 16 years. After that time, new vehicles would only be equipped with C-V2X. Because NHTSA does not supply the component costs in discounted terms, the percentage increase in cost for each year was calculated from the data provided by NHTSA in Tables VII-8 and VII-42 in (2) and then the discounted costs for each year were multiplied by this factor.

As shown in Table 7, the total cost for the base case 5-year delay, "Dual-Mode Transition" scenario, including the costs for dual-mode systems for 16 years, ranges from $58.5 billion to $100 billion, depending upon the discount rate. This compares with NHTSA's low (single radio) estimate of a total cost of $49.2 - $85.4 billion. The higher cost of the "Dual-Mode Transition" scenario is due to the dual radios during a portion of the lifetime. The "Dual-Mode Transition" only makes sense if C-V2X offers a significant advantage over DSRC. Otherwise, it makes sense to move forward with DSRC and not to swap it out for C-V2X.

*Table 8 **Total** Cost of the "Dual-Mode Transition" scenario over 40 years, in 2014 $*

	3 Year Delay	5 Year Delay	7 Year Delay
3% Discount Rate	$101 B	$100 B	$99.4 B
7% Discount Rate	$60.0 B	$58.5 B	$57.3 B

Under the assumptions described above, the costs for a C-V2X-only system is approximately the same as for a DSRC-only system. Therefore, one can take the DSRC annual costs calculated by NHTSA for the single-radio approach and shift them out by the years of delay, discounting appropriately. Then these numbers can be compared with the cost of the "Dual-Mode Transition" scenario to calculate the incremental cost increase of the "Dual-Mode Transition" scenario. The cost differentials are shown in

Table 8. The incremental costs for the base case scenario range from $17.0 billion to $21.0 billion. The detailed cost data is shown in Tables A-10 and A-11. The data in Tables A-10 and A-11 show the multiplier applied to NHTSA cost estimate to calculate the cost for the "Initial DSRC" scenario to account for the additional costs during the years of dual equipage, the "Dual-Mode Transition" costs, and then the cost for the "Wait for C-V2X" scenario. The annual cost for the "Wait for C-V2X" scenario Is the same as the NHTSA estimate for DSRC, simply shifted out the appropriately number of years and then discounted accordingly.

Table 9 Incremental Cost of "Dual-Mode Transition" vs "Wait for C-V2X, in 2014 $

	3 Year Delay	5 Year Delay	7 Year Delay
3% Discount Rate	$19.6 B	$21.0 B	$22.4 B
7% Discount Rate	$15.5 B	$17.0 B	$18.5 B

Net Benefits of the "Dual-Mode Transition" Scenario

Table 9 compares the net *total* benefits (benefits minus costs) for the "Dual-Mode Transition" scenario. As can be seen, the net total benefits are positive under all scenarios.

Table 10 Total Net Benefits, in 2014 $, of the "Dual-Mode Transition" Scenario

	3 Year Delay		5 Year Delay		7 Year Delay	
	Low	High	Low	High	Low	High
3% Discount Rate	$539 B	$759 B	$535 B	$753 B	$534 B	$751 B
7% Discount Rate	$210 B	$302 B	$211 B	$302 B	$212 B	$311 B

Table 10 shows the incremental net benefits for the "Dual-Mode Transition" Scenario vs. the "Wait for C-V2X" scenario. Again, the net benefits are positive under all scenarios.

Table 11 Incremental Net Benefits, in 2014 $, of the "Dual-Mode Transition" Scenario vs. the "Wait for C-V2X" Scenario

	3 Year Delay		5 Year Delay		7 Year Delay	
	Low	High	Low	High	Low	High
3% Discount Rate	$66.0 B	$95.4 B	$124 B	$174 B	$181 B	$251 B
7% Discount Rate	$53.9 B	$61.7 B	$69.8 B	$99.0 B	$116 B	$136 B

This initial quantitative analysis utilizes many simplifying assumptions. Further analysis should, of course, be conducted. At the same time, the approach used in this paper can be applied to examine multiple other alternatives, such as gaining a better understanding of the optimal number of years to deploy dual-mode equipment, or the cost-benefit impacts of, for example, lower C-V2X costs or increased safety benefits, should the longer range claimed for C-V2X be shown to prevent additional crashes.

Conclusions

There are both technical and policy arguments presented by both sides of the DSRC vs. C-V2X debate, and these are important. However, any consideration of the best strategy and policy needs to consider the safety benefits that are lost due to delay, as well as the costs that might be accrued should it later be desirable to convert from DSRC to C-V2X.

IT IS BENEFICIAL TO MOVE FORWARD WITH A DSRC-BASED DEPLOYMENT, SAVING THOUSANDS OF ADDITIONAL LIVES, REGARDLESS OF WHETHER A LATER TRANSITION TO C-V2X PROVES ADVANTAGEOUS.

If C-V2X offers no significant advantage over DSRC, then there is no reason not to move forward with DSRC-based connected vehicle deployment as quickly as possible, as doing otherwise costs lives. If, on the other hand, C-V2X turns out to offer some long-term advantage, then the benefits lost by waiting must be considered, and an alternative approach of beginning with DSRC and eventually transitioning to C-V2X (or some other successor technology) should be examined as an option. This paper quantitatively demonstrates that the benefits of this Dual-Mode Transition approach significantly outweigh the additional cost. *The results strengthen the argument for proceeding forward with DSRC-based deployment of V2X safety applications, rather than delaying deployment for C-V2X, even if it is later shown that C-V2X offers advantages and a long-term transition to C-V2X is desirable.* While additional analysis is needed on the impacts of a dual-mode transition, it also must be recognized that not making a decision is a decision to delay, and that further delay has a cost, in terms of lives lost, increased numbers of injuries, and greater property damage.

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Appendix

Table A- 1 Comparison of annual lives saved for Dual-Mode Transition vs. Wait for C-V2X scenarios, for the baseline 5-year delay

Deployment Year	DSRC Low Estimate	DSRC High Estimate	DSRC Average	C-V2X Low Estimate	C-V2X High Estimate	C-V2X Average	Low Delta	High Delta	Average Delta	
1	0	0	0	0	0	0	0	0	0	DSRC deployment begins
2	0	0	0	0	0	0	0	0	0	
3	2	4	3	0	0	0	2	4	3	
4	9	12	10.5	0	0	0	9	12	11	
5	23	31	27	0	0	0	23	31	27	
6	49	66	57.5	0	0	0	49	66	58	First year of dual-mode Deployment
7	88	119	103.5	0	0	0	88	119	104	
8	135	184	159.5	2	4	3	133	180	157	
9	187	255	221	9	12	10.5	178	243	211	
10	244	333	288.5	23	31	27	221	302	262	
11	302	413	357.5	49	66	57.5	253	347	300	
12	364	498	431	88	119	103.5	276	379	328	
13	426	583	504.5	135	184	159.5	291	399	345	
14	487	668	577.5	187	255	221	300	413	357	
15	547	751	649	244	333	288.5	303	418	361	
16	604	830	717	302	413	357.5	302	417	360	
17	658	905	781.5	364	498	431	294	407	351	
18	707	973	840	426	583	504.5	281	390	336	
19	751	1034	892.5	487	668	577.5	264	366	315	
20	789	1088	938.5	547	751	649	242	337	290	
21	822	1132	977	604	830	717	218	302	260	
22	740	1019	879.3	658	905	781.5	82	114	98	Last year of dual-mode deployment
23				707	973	840				First year of C-V2X only deployment

Table A- 2 Comparison of annual lives saved for Dual-Mode Transition vs. Wait for C-V2X scenarios, for a 3-year delay

Deployment Year	DSRC Low Estimate	DSRC High Estimate	DSRC Average	C-V2X Low Estimate	C-V2X High Estimate	C-V2X Average	Low Delta	High Delta	Average Delta	
1	0	0	0	0	0	0	0	0	0	DSRC deployment begins
2	0	0	0	0	0	0	0	0	0	
3	2	4	3	0	0	0	2	4	3	
4	9	12	11	0	0	0	9	12	11	First year of dual-mode Deployment
5	23	31	27	0	0	0	23	31	27	
6	49	66	58	2	4	3	47	62	55	
7	88	119	104	9	12	11	79	107	93	
8	135	184	160	23	31	27	112	153	133	
9	187	255	221	49	66	58	138	189	164	
10	244	333	289	88	119	104	156	214	185	
11	302	413	358	135	184	160	167	229	198	
12	364	498	431	187	255	221	177	243	210	
13	426	583	505	244	333	289	182	250	216	
14	487	668	578	302	413	358	185	255	220	
15	547	751	649	364	498	431	183	253	218	
16	604	830	717	426	583	505	178	247	213	
17	658	905	782	487	668	578	171	237	204	
18	707	973	840	547	751	649	160	222	191	
19	751	1034	893	604	830	717	147	204	176	
20	789	1088	939	658	905	782	131	183	157	Last year of dual-mode deployment
21	710	979	845	707	973	840	3	6	5	First year of C-V2X only deployment

Table A- 3 Comparison of annual lives saved for Dual-Mode Transition vs. Wait for C-V2X scenarios, for a 7-year delay

Deployment Year	DSRC Low Estimate	DSRC High Estimate	DSRC Average	C-V2X Low Estimate	C-V2X High Estimate	C-V2X Average	Low Delta	High Delta	Average Delta	
1	0	0	0	0	0	0	0	0	0	DSRC deployment begins
2	0	0	0	0	0	0	0	0	0	
3	2	4	3	0	0	0	2	4	3	
4	9	12	11	0	0	0	9	12	11	
5	23	31	27	0	0	0	23	31	27	
6	49	66	58	0	0	0	49	66	58	
7	88	119	104	0	0	0	88	119	104	
8	135	184	160	0	0	0	135	184	160	First year of dual-mode Deployment
9	187	255	221	0	0	0	187	255	221	
10	244	333	289	2	4	3	242	329	286	
11	302	413	358	9	12	11	293	401	347	
12	364	498	431	23	31	27	341	467	404	
13	426	583	505	49	66	58	377	517	447	
14	487	668	578	88	119	104	399	549	474	
15	547	751	649	135	184	160	412	567	490	
16	604	830	717	187	255	221	417	575	496	
17	658	905	782	244	333	289	414	572	493	
18	707	973	840	302	413	358	405	560	483	
19	751	1034	893	364	498	431	387	536	462	
20	789	1088	939	426	583	505	363	505	434	
21	822	1132	977	487	668	578	335	464	400	
22	740	1019	879	547	751	649	193	268	230	
23	751	1034	893	604	830	717	147	204	176	
24	789	1088	939	658	905	782	131	183	157	Last year of dual-mode deployment
25	710	979	845	707	973	840	3	6	5	First year of C-V2X only deployment

Table A- 4 Comparison of monetized benefits for Dual-Mode Transition vs. Wait for C-V2X scenarios, for the baseline 5-year delay (2014 $ in Millions, 3% discount rate)

Deployment Year	DSRC Low Estimate	DSRC High Estimate	DSRC Average	C-V2X Low Estimate	C-V2X High Estimate	C-V2X Average Estimate	Low Delta	High Delta	Average Delta	
1	$0	$0	$0	$0	$0	$0	$0	$0	$0	
2	$18	$24	$21	$0	$0	$0	$18	$24	$21	
3	$117	$153	$135	$0	$0	$0	$117	$153	$135	
4	$446	$583	$515	$0	$0	$0	$446	$583	$515	
5	$1,100	$1,439	$1,270	$0	$0	$0	$1,100	$1,439	$1,270	
6	$2,257	$2,961	$2,609	$0	$0	$0	$2,257	$2,961	$2,609	1st year of dual deployment
7	$3,948	$5,194	$4,571	$16	$21	$18	$3,932	$5,173	$4,553	
8	$5,914	$7,804	$6,859	$101	$132	$116	$5,813	$7,672	$6,743	
9	$7,969	$10,542	$9,256	$385	$503	$444	$7,584	$10,039	$8,812	
10	$10,071	$13,350	$11,711	$949	$1,241	$1,095	$9,122	$12,109	$10,615	
11	$12,167	$16,161	$14,164	$1,947	$2,554	$2,251	$10,220	$13,607	$11,913	
12	$14,208	$18,900	$16,554	$3,406	$4,480	$3,943	$10,802	$14,420	$12,611	
13	$16,150	$21,519	$18,835	$5,101	$6,732	$5,917	$11,049	$14,787	$12,918	
14	$17,963	$23,967	$20,965	$6,874	$9,094	$7,984	$11,089	$14,873	$12,981	
15	$19,606	$26,194	$22,900	$8,687	$11,516	$10,102	$10,919	$14,678	$12,798	
16	$21,046	$28,153	$24,600	$10,495	$13,941	$12,218	$10,551	$14,212	$12,382	
17	$22,265	$29,820	$26,043	$12,256	$16,303	$14,280	$10,009	$13,517	$11,763	
18	$23,249	$31,171	$27,210	$13,931	$18,562	$16,247	$9,318	$12,609	$10,963	
19	$23,984	$32,191	$28,088	$15,495	$20,674	$18,085	$8,489	$11,517	$10,003	
20	$24,482	$32,892	$28,687	$16,912	$22,595	$19,754	$7,570	$10,297	$8,933	
21	$24,766	$33,304	$29,035	$18,154	$24,285	$21,220	$6,612	$9,019	$7,815	
22	$24,842	$33,436	$29,139	$19,206	$25,723	$22,464	$5,636	$7,713	$6,675	Last year of dual deployment
23	$22,358	$30,092	$26,225	$20,055	$26,888	$23,472	$2,303	$3,204	$2,754	
24	$19,874	$26,749	$23,311	$20,689	$27,768	$24,229				

25	$17,389	$23,405	$20,397	$21,118	$28,373	$24,746				
26	$14,905	$20,062	$17,483	$21,363	$28,728	$25,046				
27	$12,421	$16,718		$21,429	$28,842	$25,136				
287	$9,937	$13,374		$21,358	$28,769	$25,064				
29	$7,453	$10,031		$21,187	$28,557	$24,872				
30	$4,968	$6,687		$20,924	$28,219	$24,571				
31	$2,484	$3,344		$20,609	$27,804	$24,207				
32	$0	$0		$20,259	$27,342	$23,801				
33	$0	$0		$19,883	$26,843	$23,363				
34	$0	$0		$19,492	$26,319	$22,906				
35	$0	$0		$19,083	$25,770	$22,427				
36	$0	$0		$18,654	$25,196	$21,925				
37	$0	$0		$18,223	$24,615	$21,419				
38	$0	$0		$17,778	$24,019	$20,899				
39	$0	$0		$17,336	$23,422	$20,379				
40	$0	$0		$16,891	$22,825	$19,858				

Table A- 5 Comparison of monetized benefits for Dual-Mode Transition vs. Wait for C-V2X scenarios, for 3-year delay (2014 $ in Millions, 3% discount rate)

Deployment Year	DSRC Low Estimate	DSRC High Estimate	DSRC Average	C-V2X Low Estimate	C-V2X High Estimate	C-V2X Average Estimate	Low Delta	High Delta	Average Delta	
1	$0	$0	$0	$0	$0	$0	$0	$0	$0	
2	$18	$24	$21	$0	$0	$0	$18	$24	$21	
3	$117	$153	$135	$0	$0	$0	$117	$153	$135	
4	$446	$583	$515	$0	$0	$0	$446	$583	$515	First year of dual deployment
5	$1,100	$1,439	$1,270	$16	$22	$19	$1,084	$1,417	$1,250	
6	$2,257	$2,961	$2,609	$107	$140	$124	$2,150	$2,821	$2,485	
7	$3,948	$5,194	$4,571	$408	$534	$471	$3,540	$4,660	$4,100	
8	$5,914	$7,804	$6,859	$1,007	$1,317	$1,162	$4,907	$6,487	$5,697	
9	$7,969	$10,542	$9,256	$2,065	$2,710	$2,388	$5,904	$7,832	$6,868	
10	$10,071	$13,350	$11,711	$3,613	$4,753	$4,183	$6,458	$8,597	$7,527	
11	$12,167	$16,161	$14,164	$5,412	$7,142	$6,277	$6,755	$9,019	$7,887	
12	$14,208	$18,900	$16,554	$7,293	$9,647	$8,470	$6,915	$9,253	$8,084	
13	$16,150	$21,519	$18,835	$9,216	$12,217	$10,717	$6,934	$9,302	$8,118	
14	$17,963	$23,967	$20,965	$11,135	$14,790	$12,962	$6,828	$9,177	$8,003	
15	$19,606	$26,194	$22,900	$13,002	$17,296	$15,149	$6,604	$8,898	$7,751	
16	$21,046	$28,153	$24,600	$14,780	$19,693	$17,236	$6,266	$8,460	$7,363	
17	$22,265	$29,820	$26,043	$16,439	$21,933	$19,186	$5,826	$7,887	$6,857	
18	$23,249	$31,171	$27,210	$17,942	$23,971	$20,957	$5,307	$7,200	$6,253	
19	$23,984	$32,191	$28,088	$19,260	$25,764	$22,512	$4,724	$6,427	$5,575	
20	$24,482	$32,892	$28,687	$20,376	$27,290	$23,833	$4,106	$5,602	$4,854	Last year of dual deployment
21	$22,034	$29,603	$25,818	$21,276	$28,526	$24,901	$758	$1,077	$917	
22	$19,586	$26,314	$22,950	$21,949	$29,459	$25,704				
23	$17,137	$23,024	$20,081	$22,404	$30,101	$26,253				

24	$14,689	$19,735	$17,212	$22,664	$30,478	$26,571				
25	$12,241	$16,446	$14,344	$22,734	$30,599	$26,666				
26	$9,793	$13,157	$11,475	$22,659	$30,521	$26,590				
27	$7,345	$9,868	$8,606	$22,477	$30,296	$26,386				
28	$4,896	$6,578	$5,737	$22,199	$29,937	$26,068				
29	$2,448	$3,289	$2,869	$21,865	$29,498	$25,681				
30	$0	$0	$0	$21,493	$29,007	$25,250				
31	$0	$0	$0	$21,094	$28,477	$24,786				
32	$0	$0	$0	$20,679	$27,922	$24,301				
33	$0	$0	$0	$20,246	$27,339	$23,792				
34	$0	$0	$0	$19,790	$26,730	$23,260				
35	$0	$0	$0	$19,332	$26,114	$22,723				
36	$0	$0	$0	$18,861	$25,482	$22,172				
37	$0	$0	$0	$18,392	$24,849	$21,620				
38	$0	$0	$0	$17,919	$24,215	$21,067				
39	$0	$0	$0	$17,449	$23,580	$20,515				
40	$0	$0	$0	$16,976	$22,944	$19,960				

Ta33ble A- 6 Comparison of monetized benefits for Dual-Mode Transition vs. Wait for C-V2X scenarios, for 7-year delay (2014 $ in Millions, 3% discount rate)

De3ployment Year	DSRC Low Estimate	DSRC High Estimate	DSRC Average	C-V2X Low Estimate	C-V2X High Estimate	C-V2X Average Estimate	Low Delta	High Delta	Average Delta	
1	$0	$0	$0	$0	$0	$0	$0	$0	$0	
2	$18	$24	$21	$0	$0	$0	$18	$24	$21	
3	$117	$153	$135	$0	$0	$0	$117	$153	$135	
4	$446	$583	$515	$0	$0	$0	$446	$583	$515	
5	$1,100	$1,439	$1,270	$0	$0	$0	$1,100	$1,439	$1,270	
6	$2,257	$2,961	$2,609	$0	$0	$0	$2,257	$2,961	$2,609	
7	$3,948	$5,194	$4,571	$0	$0	$0	$3,948	$5,194	$4,571	
8	$5,914	$7,804	$6,859	$0	$0	$0	$5,914	$7,804	$6,859	First year of dual deployment
9	$7,969	$10,542	$9,256	$15	$20	$17	$7,954	$10,522	$9,238	
10	$10,071	$13,350	$11,711	$95	$124	$110	$9,976	$13,226	$11,601	
11	$12,167	$16,161	$14,164	$363	$474	$418	$11,804	$15,687	$13,746	
12	$14,208	$18,900	$16,554	$894	$1,170	$1,032	$13,314	$17,730	$15,522	
13	$16,150	$21,519	$18,835	$1,835	$2,408	$2,121	$14,315	$19,111	$16,713	
14	$17,963	$23,967	$20,965	$3,210	$4,223	$3,717	$14,753	$19,744	$17,248	
15	$19,606	$26,194	$22,900	$4,809	$6,345	$5,577	$14,797	$19,849	$17,323	
16	$21,046	$28,153	$24,600	$6,480	$8,572	$7,526	$14,566	$19,581	$17,074	
17	$22,265	$29,820	$26,043	$8,189	$10,855	$9,522	$14,076	$18,965	$16,521	
18	$23,249	$31,171	$27,210	$9,893	$13,140	$11,517	$13,356	$18,031	$15,693	
19	$23,984	$32,191	$28,088	$11,552	$15,367	$13,460	$12,432	$16,824	$14,628	
20	$24,482	$32,892	$28,687	$13,131	$17,497	$15,314	$11,351	$15,395	$13,373	
21	$24,766	$33,304	$29,035	$14,606	$19,487	$17,046	$10,160	$13,817	$11,989	
22	$24,842	$33,436	$29,139	$15,941	$21,298	$18,620	$8,901	$12,138	$10,519	
23	$24,760	$33,351	$29,056	$17,112	$22,891	$20,002	$7,648	$10,460	$9,054	

24	$24,561	$33,105	$28,833	$18,103	$24,246	$21,175	$6,458	$8,859	$7,658	Last year of dual deployment
25	$22,105	$29,795	$25,950	$18,904	$25,345	$22,124	$3,201	$4,450	$3,825	
26	$19,649	$26,484	$23,066	$19,501	$26,174	$22,838	$148	$310	$229	
27	$17,193	$23,174	$20,183	$19,906	$26,744	$23,325				
28	$14,737	$19,863	$17,300	$20,137	$27,079	$23,608				
29	$12,281	$16,553	$14,417	$20,199	$27,187	$23,693				
30	$9,824	$13,242	$11,533	$20,132	$27,117	$23,625				
31	$7,368	$9,932	$8,650	$19,970	$26,917	$23,444				
32	$4,912	$6,621	$5,767	$19,723	$26,599	$23,161				
33	$2,456	$3,311	$2,883	$19,426	$26,208	$22,817				
34	$0	$0	$0	$19,096	$25,773	$22,434				
35	$0	$0	$0	$18,742	$25,302	$22,022				
36	$0	$0	$0	$18,373	$24,808	$21,591				
37	$0	$0	$0	$17,988	$24,290	$21,139				
38	$0	$0	$0	$17,583	$23,750	$20,666				
39	$0	$0	$0	$17,177	$23,202	$20,189				
40	$0	$0	$0	$16,758	$22,641	$19,699				

Table A- 7 Comparison of monetized benefits for Dual-Mode Transition vs. Wait for C-V2X scenarios, for 5-year delay (2014 $ in Millions, 7% discount rate)

Deployment Year	DSRC Low Estimate	DSRC High Estimate	DSRC Average	C-V2X Low Estimate	C-V2X High Estimate	C-V2X Average Estimate	Low Delta	High Delta	Average Delta	
1	$0	$0	$0	$0	$0	$0	$0	$0	$0	
2	$17	$23	$20	$0	$0	$0	$17	$23	$20	
3	$107	$139	$123	$0	$0	$0	$107	$139	$123	
4	$390	$510	$450	$0	$0	$0	$390	$510	$450	
5	$927	$1,212	$1,070	$0	$0	$0	$927	$1,212	$1,070	
6	$1,830	$2,401	$2,116	$0	$0	$0	$1,830	$2,401	$2,116	First dual deployment
7	$3,082	$4,055	$3,569	$12	$16	$14	$3,070	$4,039	$3,554	
8	$4,443	$5,864	$5,154	$76	$99	$88	$4,367	$5,765	$5,066	
9	$5,764	$7,625	$6,695	$278	$364	$321	$5,486	$7,261	$6,374	
10	$7,012	$9,295	$8,154	$661	$864	$763	$6,351	$8,431	$7,391	
11	$8,155	$10,831	$9,493	$1,305	$1,712	$1,508	$6,850	$9,119	$7,985	
12	$9,167	$12,196	$10,682	$2,197	$2,891	$2,544	$6,970	$9,305	$8,137	
13	$10,031	$13,364	$11,698	$3,168	$4,181	$3,674	$6,863	$9,183	$8,023	
14	$10,740	$14,330	$12,535	$4,110	$5,437	$4,773	$6,630	$8,893	$7,762	
15	$11,284	$15,075	$13,180	$4,999	$6,627	$5,813	$6,285	$8,448	$7,366	
16	$11,661	$15,600	$13,631	$5,814	$7,722	$6,768	$5,847	$7,878	$6,862	
17	$11,876	$15,905	$13,891	$6,536	$8,696	$7,616	$5,340	$7,209	$6,275	
18	$11,934	$16,001	$13,968	$7,152	$9,528	$8,340	$4,782	$6,473	$5,627	
19	$11,851	$15,907	$13,879	$7,657	$10,217	$8,937	$4,194	$5,690	$4,942	
20	$11,647	$15,647	$13,647	$8,045	$10,748	$9,397	$3,602	$4,899	$4,250	
21	$11,339	$15,248	$13,294	$8,314	$11,123	$9,718	$3,025	$4,125	$3,575	
22	$10,950	$14,739	$12,845	$8,467	$11,340	$9,904	$2,483	$3,399	$2,941	Last dual deployment
23	$9,855	$13,265	$11,560	$8,509	$11,408	$9,959	$1,346	$1,857	$1,601	

24	$8,760	$11,791	$10,276	$8,450	$11,341	$9,896				
25	$7,665	$10,317	$8,991	$8,304	$11,156	$9,730				
26	$6,570	$8,843	$7,707	$8,085	$10,872	$9,478				
27	$5,475	$7,370		$7,807	$10,509	$9,158				
28	$4,380	$5,896		$7,491	$10,090	$8,791				
29	$3,285	$4,422		$7,151	$9,640	$8,395				
30	$2,190	$2,948		$6,801	$9,171	$7,986				
31	$1,095	$1,474		$6,447	$8,698	$7,572				
32	$0	$0		$6,102	$8,236	$7,169				
33	$0	$0		$5,765	$7,782	$6,774				
34	$0	$0		$5,439	$7,344	$6,391				
35	$0	$0		$5,127	$6,923	$6,025				
36	$0	$0		$4,824	$6,516	$5,670				
37	$0	$0		$4,537	$6,128	$5,332				
38	$0	$0		$4,259	$5,755	$5,007				
39	$0	$0		$4,000	$5,404	$4,702				
40	$0	$0		$3,750	$5,068	$4,409				

Table A- 8 Comparison of monetized benefits for Dual-Mode Transition vs. Wait for C-V2X scenarios, for 3-year delay (2014 $ in Millions, 7% discount rate)

Deployment Year	DSRC Low Estimate	DSRC High Estimate	DSRC Average	C-V2X Low Estimate	C-V2X High Estimate	C-V2X Average Estimate	Low Delta	High Delta	Average Delta	
1	$0	$0	$0	$0	$0	$0	$0	$0	$0	
2	$17	$23	$20	$0	$0	$0	$17	$23	$20	
3	$107	$139	$123	$0	$0	$0	$107	$139	$123	
4	$390	$510	$450	$0	$0	$0	$390	$510	$450	First dual deployment
5	$927	$1,212	$1,070	$14	$19	$16	$913	$1,193	$1,053	
6	$1,830	$2,401	$2,116	$87	$113	$100	$1,743	$2,288	$2,015	
7	$3,082	$4,055	$3,569	$318	$416	$367	$2,764	$3,639	$3,201	
8	$4,443	$5,864	$5,154	$757	$989	$873	$3,686	$4,875	$4,280	
9	$5,764	$7,625	$6,695	$1,494	$1,960	$1,727	$4,270	$5,665	$4,968	
10	$7,012	$9,295	$8,154	$2,516	$3,310	$2,913	$4,496	$5,985	$5,241	
11	$8,155	$10,831	$9,493	$3,627	$4,787	$4,207	$4,528	$6,044	$5,286	
12	$9,167	$12,196	$10,682	$4,705	$6,224	$5,465	$4,462	$5,972	$5,217	
13	$10,031	$13,364	$11,698	$5,724	$7,587	$6,656	$4,307	$5,777	$5,042	
14	$10,740	$14,330	$12,535	$6,657	$8,841	$7,749	$4,083	$5,489	$4,786	
15	$11,284	$15,075	$13,180	$7,483	$9,956	$8,719	$3,801	$5,119	$4,460	
16	$11,661	$15,600	$13,631	$8,188	$10,909	$9,549	$3,473	$4,691	$4,082	
17	$11,876	$15,905	$13,891	$8,767	$11,698	$10,232	$3,109	$4,207	$3,658	
18	$11,934	$16,001	$13,968	$9,211	$12,306	$10,758	$2,723	$3,695	$3,209	
19	$11,851	$15,907	$13,879	$9,519	$12,734	$11,127	$2,332	$3,173	$2,752	
20	$11,647	$15,647	$13,647	$9,694	$12,983	$11,339	$1,953	$2,664	$2,308	Last dual deployment
21	$10,482	$14,082	$12,282	$9,742	$13,062	$11,402	$741	$1,021	$881	
22	$9,318	$12,518	$10,918	$9,674	$12,985	$11,329				
23	$8,153	$10,953	$9,553	$9,507	$12,773	$11,140				
24	$6,988	$9,388	$8,188	$9,256	$12,447	$10,851				

25	$5,824	$7,824	$6,824	$8,938	$12,031	$10,485				
26	$4,659	$6,259	$5,459	$8,577	$11,552	$10,065				
27	$3,494	$4,694	$4,094	$8,187	$11,036	$9,612				
28	$2,329	$3,129	$2,729	$7,787	$10,500	$9,143				
29	$1,165	$1,565	$1,365	$7,381	$9,958	$8,669				
30	$0	$0	$0	$6,986	$9,429	$8,207				
31	$0	$0	$0	$6,601	$8,910	$7,755				
32	$0	$0	$0	$6,227	$8,408	$7,317				
33	$0	$0	$0	$5,870	$7,926	$6,898				
34	$0	$0	$0	$5,523	$7,460	$6,492				
35	$0	$0	$0	$5,194	$7,016	$6,105				
36	$0	$0	$0	$4,877	$6,588	$5,732				
37	$0	$0	$0	$4,579	$6,188	$5,383				
38	$0	$0	$0	$4,294	$5,802	$5,048				
39	$0	$0	$0	$4,022	$5,436	$4,729				
40	$0	$0	$0	$3,768	$5,092	$4,430				

Table 12 Comparison of monetized benefits for Dual-Mode Transition vs. Wait for C-V2X scenarios, for 7-year delay (2014 $ in Millions, 7% discount rate)

Deployment Year	DSRC Low Estimate	DSRC High Estimate	DSRC Average	C-V2X Low Estimate	C-V2X High Estimate	C-V2X Average Estimate	Low Delta	High Delta	Average Delta	
1	$0	$0	$0	$0	$0	$0	$0	$0	$0	
2	$17	$23	$20	$0	$0	$0	$17	$23	$20	
3	$107	$139	$123	$0	$0	$0	$107	$139	$123	
4	$390	$510	$450	$0	$0	$0	$390	$510	$450	
5	$927	$1,212	$1,070	$0	$0	$0	$927	$1,212	$1,070	
6	$1,830	$2,401	$2,116	$0	$0	$0	$1,830	$2,401	$2,116	
7	$3,082	$4,055	$3,569	$0	$0	$0	$3,082	$4,055	$3,569	
8	$4,443	$5,864	$5,154	$0	$0	$0	$4,443	$5,864	$5,154	First dual deployment
9	$5,764	$7,625	$6,695	$11	$14	$12	$5,753	$7,611	$6,682	
10	$7,012	$9,295	$8,154	$67	$87	$77	$6,945	$9,208	$8,077	
11	$8,155	$10,831	$9,493	$243	$318	$280	$7,912	$10,513	$9,213	
12	$9,167	$12,196	$10,682	$577	$755	$666	$8,590	$11,441	$10,015	
13	$10,031	$13,364	$11,698	$1,140	$1,495	$1,317	$8,891	$11,869	$10,380	
14	$10,740	$14,330	$12,535	$1,919	$2,525	$2,222	$8,821	$11,805	$10,313	
15	$11,284	$15,075	$13,180	$2,767	$3,652	$3,209	$8,517	$11,423	$9,970	
16	$11,661	$15,600	$13,631	$3,590	$4,748	$4,169	$8,071	$10,852	$9,462	
17	$11,876	$15,905	$13,891	$4,367	$5,788	$5,078	$7,509	$10,117	$8,813	
18	$11,934	$16,001	$13,968	$5,079	$6,745	$5,912	$6,855	$9,256	$8,056	
19	$11,851	$15,907	$13,879	$5,709	$7,595	$6,652	$6,142	$8,312	$7,227	
20	$11,647	$15,647	$13,647	$6,247	$8,322	$7,285	$5,400	$7,325	$6,362	
21	$11,339	$15,248	$13,294	$6,688	$8,924	$7,806	$4,651	$6,324	$5,487	
22	$10,950	$14,739	$12,845	$7,027	$9,388	$8,208	$3,923	$5,351	$4,637	
23	$10,507	$14,152	$12,330	$7,262	$9,715	$8,488	$3,245	$4,437	$3,841	

24	$10,030	$13,520	$11,775	$7,396	$9,905	$8,650	$2,634	$3,615	$3,125	Last dual deployment
25	$9,027	$10,816	$9,922	$7,432	$9,965	$8,698	$1,595	$851	$1,223	
26	$8,024	$9,464	$8,744	$7,380	$9,906	$8,643				
27	$7,021	$8,112	$7,567	$7,253	$9,744	$8,499				
28	$6,018	$6,760	$6,389	$7,061	$9,496	$8,279				
29	$5,015	$5,408	$5,212	$6,819	$9,179	$7,999				
30	$4,012	$4,056	$4,034	$6,543	$8,813	$7,678				
31	$3,009	$2,704	$2,857	$6,246	$8,420	$7,333				
32	$2,006	$1,352	$1,679	$5,940	$8,010	$6,975				
33	$1,003	$0	$502	$5,631	$7,597	$6,614				
34	$0	$0	$0	$5,329	$7,193	$6,261				
35	$0	$0	$0	$5,036	$6,797	$5,916				
36	$0	$0	$0	$4,750	$6,414	$5,582				
37	$0	$0	$0	$4,478	$6,047	$5,263				
38	$0	$0	$0	$4,214	$5,691	$4,952				
39	$0	$0	$0	$3,963	$5,353	$4,658				
40	$0	$0	$0	$3,720	$5,026	$4,373				

Table A- 9 Calculation of the Differential Cost for Dual Mode Systems, using constant year $ taken from Table VII-8 and VII-19 in NHTSA's preliminary analysis report

Year	Apps	1 Radio	2 Radios	Differential Cost of 2nd Radio	20% of Apps Cost	Annual Cost of Single Mode	Percent Delta for Dual Mode
1	$0.00	$2,000.92	$2,821.67	$820.75	$0.00	$2,191.73	**137%**
2	$0.61	$2,751.72	$3,879.94	$1,128.22	$0.12	$3,011.39	**137%**
3	$1.64	$3,470.84	$4,893.35	$1,422.51	$0.33	$3,832.35	**137%**
4	$4.13	$3,360.54	$4,736.34	$1,375.80	$0.83	$3,741.15	**137%**
5	$6.67	$3,297.19	$4,645.68	$1,348.49	$1.33	$3,701.10	**136%**
6	$10.89	$3,244.74	$4,569.60	$1,324.86	$2.18	$3,655.18	**136%**
7	$15.19	$3,214.60	$4,525.12	$1,310.52	$3.04	$3,640.20	**136%**
8	$17.03	$3,193.60	$4,494.87	$1,301.27	$3.41	$3,634.16	**136%**
9	$17.13	$3,167.72	$4,458.56	$1,290.84	$3.43	$3,622.11	**136%**
10	$17.30	$3,159.58	$4,447.19	$1,287.61	$3.46	$3,649.18	**135%**
11	$17.44	$3,149.66	$4,433.29	$1,283.63	$3.49	$3,659.33	**135%**
12	$17.56	$3,139.20	$4,418.61	$1,279.41	$3.51	$3,662.06	**135%**
13	$17.67	$3,129.51	$4,405.01	$1,275.50	$3.53	$3,665.05	**135%**
14	$17.84	$3,132.41	$4,409.12	$1,276.71	$3.57	$3,682.06	**135%**
15	$18.00	$3,135.14	$4,412.99	$1,277.85	$3.60	$3,717.37	**134%**
16	$18.16	$3,139.24	$4,418.78	$1,279.54	$3.63	$3,713.49	**135%**
17	$18.34	$3,147.91	$4,431.00	$1,283.09	$3.67	$3,733.84	**134%**
18	$18.49	$3,152.45	$4,437.40	$1,284.95	$3.70	$3,749.02	**134%**
19	$18.66	$3,161.27	$4,449.84	$1,288.57	$3.73	$3,768.99	**134%**
20	$18.87	$3,177.54	$4,472.75	$1,295.21	$3.77	$3,830.85	**134%**
21	$19.14	$3,204.34	$4,510.49	$1,306.15	$3.83	$3,856.11	**134%**
22	$18.56	$3,090.70	$4,350.52	$1,259.82	$3.71	$3,737.09	**134%**
23	$18.66	$3,091.52	$4,351.69	$1,260.17	$3.73	$3,744.45	**134%**
24	$18.76	$3,092.91	$4,353.66	$1,260.75	$3.75	$3,751.94	**134%**

25	$18.87	$3,096.45	$4,358.65	$1,262.20	$3.77	$3,795.51	**133%**
26	$18.97	$3,098.81	$4,361.98	$1,263.17	$3.79	$3,769.63	**134%**
27	$19.08	$3,103.22	$4,368.19	$1,264.97	$3.82	$3,779.91	**134%**
28	$19.18	$3,106.39	$4,372.65	$1,266.26	$3.84	$3,788.76	**134%**
29	$19.28	$3,109.91	$4,377.61	$1,267.70	$3.86	$3,797.35	**133%**
30	$19.39	$3,115.37	$4,385.30	$1,269.93	$3.88	$3,858.10	**133%**
31	$19.39	$3,103.57	$4,368.70	$1,265.13	$3.88	$3,821.57	**133%**
32	$19.39	$3,092.23	$4,352.74	$1,260.51	$3.88	$3,813.29	**133%**
33	$19.39	$3,081.32	$4,337.38	$1,256.06	$3.88	$3,805.14	**133%**
34	$19.39	$3,070.79	$4,322.57	$1,251.78	$3.88	$3,797.21	**133%**
35	$19.39	$3,060.63	$4,308.27	$1,247.64	$3.88	$3,832.35	**133%**
36	$19.39	$3,050.82	$4,294.46	$1,243.64	$3.88	$3,782.22	**133%**
37	$19.39	$3,041.33	$4,281.11	$1,239.78	$3.88	$3,775.03	**133%**
38	$19.39	$3,032.14	$4,268.17	$1,236.03	$3.88	$3,767.82	**133%**
39	$19.39	$3,023.24	$4,255.64	$1,232.40	$3.88	$3,760.74	**133%**
40	$19.39	$3,014.60	$4,243.49	$1,228.89	$3.88	$3,804.29	**132%**

Table A- 10 Annual Costs in 2014 $, Using 3% Discount Rate, for the "Dual-Mode Transition" and Wait for C-V2X Scenarios

Year	3 Year Delay			5 Year Delay			7 YR SHIFT COSTS		
	Multiplier	Cost for "Dual-Mode Transition Scenario"	Cost for "Wait for C-V2X" Scenario	Multiplier	Cost for "Dual-Mode Transition Scenario"	Cost for "Wait for C-V2X" Scenario	Multiplier	Cost for "Dual-Mode Transition Scenario"	Cost for "Wait for C-V2X" Scenario
1	100%	$2,160		100%	$2,160		100%	$2,160	
2	100%	$2,880		100%	$2,880		100%	$2,880	
3	100%	$3,560		100%	$3,560		100%	$3,560	
4	137%	$4,614	$1,977	100%	$3,373		100%	$3,373	
5	136%	$4,422	$2,636	100%	$3,240		100%	$3,240	
6	136%	$4,235	$3,258	136%	$4,235	$1,863	100%	$3,107	
7	136%	$4,088	$3,087	136%	$4,088	$2,484	100%	$3,004	
8	136%	$3,957	$2,965	136%	$3,957	$3,071	136%	$3,957	$1,756
9	136%	$3,824	$2,843	136%	$3,824	$2,910	136%	$3,824	$2,342
10	135%	$3,731	$2,749	135%	$3,731	$2,795	135%	$3,731	$2,895
11	135%	$3,627	$2,665	135%	$3,627	$2,680	135%	$3,627	$2,743
12	135%	$3,520	$2,578	135%	$3,520	$2,591	135%	$3,520	$2,634
13	135%	$3,417	$2,522	135%	$3,417	$2,512	135%	$3,417	$2,526
14	135%	$3,329	$2,455	135%	$3,329	$2,430	135%	$3,329	$2,443
15	134%	$3,257	$2,386	134%	$3,257	$2,377	134%	$3,257	$2,368
16	135%	$3,159	$2,318	135%	$3,159	$2,314	135%	$3,159	$2,290
17	134%	$3,083	$2,260	134%	$3,083	$2,249	134%	$3,083	$2,241
18	134%	$3,003	$2,216	134%	$3,003	$2,185	134%	$3,003	$2,182
19	134%	$2,929	$2,149	134%	$2,929	$2,131	134%	$2,929	$2,120
20	134%	$2,883	$2,098	134%	$2,883	$2,089	134%	$2,883	$2,060
21	100%	$2,103	$2,045	134%	$2,818	$2,025	134%	$2,818	$2,008

22	100%	$1,980	$1,996	134%	$2,653	$1,978	134%	$2,653	$1,969
23	100%	$1,925	$1,970	100%	$1,925	$1,928	134%	$2,580	$1,909
24	100%	$1,874	$1,925	100%	$1,874	$1,881	134%	$2,511	$1,864
25	100%	$1,839	$1,812	100%	$1,839	$1,857	100%	$1,839	$1,817
26	100%	$1,774	$1,762	100%	$1,774	$1,814	100%	$1,774	$1,773
27	100%	$1,727	$1,715	100%	$1,727	$1,708	100%	$1,727	$1,751
28	100%	$1,681	$1,683	100%	$1,681	$1,661	100%	$1,681	$1,710
29	100%	$1,636	$1,623	100%	$1,636	$1,617	100%	$1,636	$1,610
30	100%	$1,613	$1,580	100%	$1,613	$1,586	100%	$1,613	$1,565
31	100%	$1,551	$1,538	100%	$1,551	$1,530	100%	$1,551	$1,524
32	100%	$1,503	$1,497	100%	$1,503	$1,490	100%	$1,503	$1,495
33	100%	$1,456	$1,476	100%	$1,456	$1,450	100%	$1,456	$1,442
34	100%	$1,410	$1,419	100%	$1,410	$1,411	100%	$1,410	$1,404
35	100%	$1,383	$1,375	100%	$1,383	$1,391	100%	$1,383	$1,367
36	100%	$1,324	$1,332	100%	$1,324	$1,338	100%	$1,324	$1,330
37	100%	$1,284	$1,290	100%	$1,284	$1,297	100%	$1,284	$1,312
38	100%	$1,243	$1,266	100%	$1,243	$1,256	100%	$1,243	$1,261
39	100%	$1,206	$1,212	100%	$1,206	$1,216	100%	$1,206	$1,222
40	100%	$1,183	$1,175	100%	$1,183	$1,193	100%	$1,183	$1,184
41			$1,138			$1,142			$1,146
42			$1,104			$1,108			$1,125
43			$1,083			$1,072			$1,077
44						$1,040			$1,044
45						$1,020			$1,011
46									$981
47									$962

Table A- 11 Annual Costs in 2014 $, Using 7% Discount Rate, for the "Dual-Mode Transition" and Wait for C-V2X Scenarios

Year	3 Year Delay			5 Year Delay			7 YR SHIFT COSTS		
	Multiplier	Cost for "Dual-Mode Transition Scenario"	Cost for "Wait for C-V2X" Scenario	Multiplier	Cost for "Dual-Mode Transition Scenario"	Cost for "Wait for C-V2X" Scenario	Multiplier	Cost for "Dual-Mode Transition Scenario"	Cost for "Wait for C-V2X" Scenario
1	100%	$2,119		100%	$2,119		100%	$2,119	
2	100%	$2,721		100%	$2,721		100%	$2,721	
3	100%	$3,236		100%	$3,236		100%	$3,236	
4	137%	$4,038	$1,730	100%	$2,952		100%	$2,952	
5	136%	$3,724	$2,221	100%	$2,729		100%	$2,729	
6	136%	$3,435	$2,642	136%	$3,435	$1,511	100%	$2,520	
7	136%	$3,191	$2,410	136%	$3,191	$1,940	100%	$2,345	
8	136%	$2,973	$2,228	136%	$2,973	$2,307	136%	$2,973	$1,320
9	136%	$2,765	$2,057	136%	$2,765	$2,105	136%	$2,765	$1,695
10	135%	$2,598	$1,914	135%	$2,598	$1,946	135%	$2,598	$2,015
11	135%	$2,430	$1,786	135%	$2,430	$1,797	135%	$2,430	$1,838
12	135%	$2,271	$1,663	135%	$2,271	$1,672	135%	$2,271	$1,699
13	135%	$2,122	$1,566	135%	$2,122	$1,560	135%	$2,122	$1,569
14	135%	$1,992	$1,468	135%	$1,992	$1,452	135%	$1,992	$1,460
15	134%	$1,873	$1,373	134%	$1,873	$1,368	134%	$1,873	$1,363
16	135%	$1,751	$1,284	135%	$1,751	$1,282	135%	$1,751	$1,269
17	134%	$1,644	$1,206	134%	$1,644	$1,199	134%	$1,644	$1,195
18	134%	$1,541	$1,137	134%	$1,541	$1,122	134%	$1,541	$1,120
19	134%	$1,448	$1,062	134%	$1,448	$1,054	134%	$1,448	$1,047
20	134%	$1,371	$998	134%	$1,371	$993	134%	$1,371	$980
21	100%	$964	$936	134%	$1,292	$928	134%	$1,292	$920

22	100%	$872	$880	134%	$1,168	$872	134%	$1,168	$867
23	100%	$817	$836	100%	$817	$818	134%	$1,095	$810
24	100%	$765	$787	100%	$765	$769	134%	$1,025	$762
25	100%	$724	$712	100%	$724	$730	100%	$724	$714
26	100%	$671	$667	100%	$671	$687	100%	$671	$671
27	100%	$629	$624	100%	$629	$622	100%	$629	$638
28	100%	$590	$591	100%	$590	$583	100%	$590	$600
29	100%	$552	$548	100%	$552	$545	100%	$552	$543
30	100%	$524	$513	100%	$524	$516	100%	$524	$509
31	100%	$486	$482	100%	$486	$478	100%	$486	$476
32	100%	$452	$451	100%	$452	$448	100%	$452	$451
33	100%	$422	$428	100%	$422	$421	100%	$422	$418
34	100%	$394	$397	100%	$394	$394	100%	$394	$392
35	100%	$372	$369	100%	$372	$374	100%	$372	$367
36	100%	$342	$344	100%	$342	$347	100%	$342	$344
37	100%	$319	$322	100%	$319	$322	100%	$319	$326
38	100%	$298	$304	100%	$298	$301	100%	$298	$303
39	100%	$278	$279	100%	$278	$281	100%	$278	$281
40	100%	$263	$260	100%	$263	$265	100%	$263	$263
41			$243		$58,521	$244		$57,298	$245
42			$227			$227			$232
43			$215			$212			$213
44						$198			$199
45						$188			$186
46									$173
47									$164