# The Impact of a Vehicle-to-Vehicle Communications Rulemaking on Growth in the DSRC Automotive Aftermarket

## A Market Adoption Model and Forecast for Dedicated Short Range Communications (DSRC) for Light and Heavy Vehicle Categories

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## Notice

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The focus of this project was to estimate the potential impact of a new motor vehicle government mandate for vehicle-to-vehicle (V2V) technology on the demand for aftermarket devices, applications, and infrastructure that leverages the same dedicated short range communications (DSRC) technology upon which V2V is based. The report leverages findings from interviews with numerous industry stakeholders, as well as research of analogous automotive and personal electronic devices, to forecast the potential growth of DSRC devices and services that may result from a government mandate of V2V technology.

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**List of Acronyms**

| | |
|---|---|
| 3GPP | Third Generation Partnership Project |
| ADAS | Advanced Driver Assistance Systems |
| ANPRM | Advance Notice of Proposed Rulemaking |
| ASD | Advanced Safety Device |
| BLE | Bluetooth Low Energy |
| CAMP | Crash Avoidance Metrics Partnerships |
| CAN | Controller Area Network |
| CE | Consumer Electronics |
| CVRIA | Connected Vehicle Reference Implementation Architecture |
| DSRC | Dedicated Short Range Communication |
| EEBL | Emergency Electronic Brake Light |
| FCC | Federal Communications Commission |
| FHWA | Federal Highway Administration |
| FMVSS | Federal Motor Vehicle Safety Standards |
| GM | General Motors |
| GPS | Global Positioning System |
| ITS | Intelligent Transportation Systems |
| LAN | Local Access Network |
| LTE | Long Term Evolution |
| MAC | Media Access Control |
| MPO | Metropolitan Planning Organization |
| NHTSA | National Highway Traffic Safety Administration |
| OBE | On-Board Equipment |
| OBU | On-Board Unit |
| OEM | Original Equipment Manufacturer |
| PND | Personal Navigation Device |
| RAN | Radio Access Network |
| RAT | Radio Access Technology |
| RFP | Request for Proposal |
| RSE | Roadside Equipment |
| RSU | Roadside Unit |
| SMP | Short Message Protocol |
| SPaT | Signal Phase and Timing |
| TCP-IP | Transmission Control Protocol-Internet Protocol |
| US DOT | United States Department of Transportation |
| V2I | Vehicle-to-Infrastructure |
| V2V | Vehicle-to-Vehicle |
| V2X | Vehicle-to-Vehicle/Device/Infrastructure |
| VAD | Vehicle Awareness Device |
| VIIC | Vehicle Infrastructure Integration Consortium |
| VMT | Vehicle Miles Traveled |
| WAVE | Wireless Access for Vehicular Environment |
| WOM | Word of Mouth |

# Executive Summary

The focus of this project was to estimate the potential impact of a new government mandate for vehicle-to-vehicle (V2V) technology on the demand for aftermarket devices, applications, and infrastructure that utilize the same Dedicated Short Range Communications (DSRC) technology upon which V2V is based. The report leverages findings from interviews with numerous industry stakeholders, as well as research on analogous automotive and personal electronic devices, to forecast the potential growth of DSRC devices and services that may result from a government mandate of V2V technology.

Aftermarket and consumer electronics have driven incredible innovation in the transportation sector. The widespread adoption of computer aided dispatch systems in commercial freight and passenger fleets in the 1980s and 1990s was eclipsed only by the explosion of personal navigation devices in the 1990s and 2000s.

The 2010s brought these capabilities to a new form factor, GPS-enabled "app phones," and expanded the universe of routing and other safety and mobility applications ("apps") to support niche needs. Because aftermarket and consumer electronics have driven so many efficiencies in road transportation, this report seeks to describe the broader positive market impact of a potential rulemaking by the National Highway Traffic Safety Administration (NHTSA) that would mandate vehicle-to-vehicle DSRC technology in new motor vehicles.

Already, a number of firms produce DSRC chipsets, modules, and devices in three categories – factory original equipment, auto aftermarket/consumer electronics, and roadside units for integration with traffic signals and other highway traffic management systems. Because NHTSA regulatory authority only applies to new vehicles and motor vehicle equipment, a V2V rulemaking would only directly affect vehicle factory installations of DSRC. At first glance, it would appear that the impact of a V2V rule would be limited only to the market for automotive Original Manufactured Equipment. This report concludes that because the industry views aftermarket/consumer electronics as a potentially large and lucrative market, even a NHTSA rule that sought only to mandate V2V communications capability in new motor vehicles, would still likely kick-start investment in DSRC-based aftermarket/consumer electronics devices and roadside infrastructure, as well as associated safety, mobility, and other applications that leverage the particular functional and technical advantages of DSRC.

In order to determine the timeframe for this new market, this report features a market adoption model and forecast for all categories of vehicle-to-vehicle/infrastructure/device (known together as V2X) equipment and apps. The development of the market adoption model was informed by a series of interviews with various stakeholders in the auto, consumer electronics, road infrastructure equipment, and service sectors. Results from those interviews were used to design the market adoption model for DSRC documented in this report. This market adoption model reflects interviewees' best understanding and points of view on the potential market size and growth for all DSRC equipment and applications across all sectors, devices, and application categories.

Previous market adoption models have concluded that even under a potential NHTSA V2V rule mandating DSRC for all vehicles, it would take several decades before DSRC could be found in a majority of existing vehicles – assuming no aftermarket /consumer electronics equipage and existing low rates of new vehicle sales and vehicle scrappage. However, with aftermarket/consumer electronics producing V2V- capable devices, the timeframe for having V2V in 80% of vehicles is reduced by fifteen years.

The market adoption model in this report describes dramatic growth in DSRC-based aftermarket consumer electronics. Key highlights are:

- **By 2029, seven years after the projected phase-in of the light vehicle V2V rule, 60% of all vehicles, or a cumulative 146 million cars, will have DSRC/V2X equipment.** This equipment will be either NHTSA V2V standard installations in newly manufactured light and heavy vehicles, or aftermarket/consumer electronics DSRC V2X devices for existing vehicles.

- **Adoption of aftermarket/consumer electronics DSRC devices will outpace factory installed DSRC within five to six years after a NHTSA Light Vehicle V2V rule requiring 100% of all new vehicles to be equipped with V2V**. Growth of DSRC V2V aftermarket/consumer electronics will accelerate to double the rate of factory-installed sales.

The market adoption model and forecast also takes into consideration inertia in consumer attitudes, as adoption of new DSRC/V2X aftermarket and consumer devices is voluntary and some categories of consumers will be slow to adopt the new technology. The model assumes that as more and more vehicles are equipped, consumer word-of-mouth, network effects, and growth in vehicle-to-vehicle and vehicle-to-infrastructure (V2I) applications overcome this inertia as the utility of a V2X network and application platform grows.

Network effects dominate V2X market adoption during early growth stages. According to Metcalfe's Law, the value of the telecommunications network is proportional to the square of the total number of connected nodes. In the market adoption model, this virtuous circle is kick-started by the assumed NHTSA rulemaking requiring light and heavy duty vehicles be equipped by DSRC for V2V, until critical mass is reached through aftermarket/consumer electronics devices and expansion of new V2X applications, in particular vehicle-to-infrastructure deployments and applications.

Furthermore, the market adoption model and forecast also address how growth is driven by the development of a DSRC/V2X application platform. The notion of a vehicle as a new "app platform" similar to the mobile phone is strongly supported based on recent initiatives by automakers, who are expanding the use of over-the-air software updates to add or improve features. In a similar way, DSRC/V2X architecture is designed to provision and manage multiple services over time, and the model takes this "platform growth effect" into account.

The market adoption model excludes growth in V2X apps that cannot be attributed exclusively to the DSRC platform. The market model only includes growth driven by V2X apps which require short hop, peer-to-peer, and low latency communications, without additional routing or other intermediation through cellular or other wireless internet service providers. The forecast also shows that even if public investments at the state and local level in vehicle-to-infrastructure DSRC are delayed significantly, a NHTSA V2V rulemaking may be expected to be enough impetus to accelerate market adoption.

The forecast in this report matches historical growth patterns for past auto technologies. Adoption of new auto technology in consumer electronics channels is not instantaneous, but can be dramatic when it does take off. It took a little over a decade between when GPS navigation was first introduced as optional equipment by carmakers in the 1990s, to when the market for personal navigation devices became saturated in the consumer electronics product category in the latter 2000s. In a similar fashion, the creation of a market for aftermarket/consumer electronics DSRC V2X applications will be spurred by progress made in the auto industry following NHTSA rulemakings.

# Introduction

In the 2014 *Federal Motor Vehicle Safety Standards: Vehicle-to-Vehicle (V2V) Communications Advance Notice of Proposed Rulemaking* (ANPRM), the National Highway Traffic Safety Administration (NHTSA) asked the public to comment on whether a V2V standard should be promulgated by the agency. A key question for the agency was whether a requirement for V2V capability in all light vehicles was necessary and sufficient to ensure the safety benefits from Dedicated Short Range Communications (DSRC) networking technology.

The U.S. Department of Transportation's (US DOT) Connected Vehicle Program seeks to ensure that vehicle-to-vehicle/infrastructure/device (V2X) communications are available to support crash avoidance, mobility, and other intelligent transportation applications. Crash avoidance applications which utilize DSRC are currently being designed to securely and anonymously exchange safety and other critical data among all road users and road operators. DSRC could be installed in vehicles, and integrated into traffic control systems, with the goal of reducing the risk of dangerous collisions or other disruptions to road user mobility.

> *"If V2V gets mandated, regardless of technology, it will only help perpetuate the whole idea of the intelligent situationally aware vehicle"*
> **Technology Executive at a major semiconductor manufacturer**

DSRC is wireless technology that enables reliable, low-latency, 1000 meter range communications between radio terminals moving at highway speeds. The Federal Communications Commission (FCC) allocated 75 MHz of spectrum in the 5.9 GHz band for Intelligent Transportation Services. This established a standard to ensure interoperability between road user equipment (on-board units, or OBUs), and road operator equipment (roadside units, or RSUs), and reserved channels for general intelligent transportation applications, as well as sensitive "safety-of-life" and public safety operations.

This report describes a future market for DSRC terminal equipment and applications. The report describes a market adoption model and provides a forecast of DSRC equipage and applications based on this model, assuming a NHTSA V2V rule for all newly manufactured light and heavy vehicles. It is assumed the NHTSA V2V light vehicle rule would require all new vehicles to come factory-installed with DSRC, followed in time with a similar requirement for heavy duty vehicles. NHTSA currently does not envision concurrently mandating safety applications. NHTSA believes the DSRC radio platform and communications standards will foster innovative and competitive safety applications development among vehicle Original Equipment Manufacturers (OEMs), tech and aftermarket/consumer electronics hardware/application providers.

The market adoption model used in this study describes how innovation will be built upon deployment of DSRC. The model simulates direct demand-side economies of scale, defined as the effect whereby the more users using a networked platform, the more valuable the platform becomes. In addition, other "indirect" network effects are also included. These other network effects are parameterized in the model, such as how the growth of DSRC applications influences the growth of DSRC equipage in vehicles.

The market adoption model is based upon well-understood models for mobile broadband equipment and application platforms, such as cellular or Wi-Fi. In particular, multiple wireless hardware form factors are taken into consideration. For the report's model, DSRC form factors include all classes of vehicles (except motorcycles), consumer-grade mobile and auto-aftermarket devices, and industrial-grade roadside devices.

This report indicates that a potential light vehicle V2V rule can kick-start market acceptance of DSRC directly through a mandate for new vehicle equipage, and indirectly through the consumer electronics/auto-aftermarket (CE/aftermarket). The model developed in this report shows how market forces, driven by the mandate, may be expected to grow DSRC device and application penetration far beyond what could be achieved through voluntary adoption by vehicle manufacturers alone, and what the timing and magnitude could be. Although large commercial vehicles are less than ten percent of new vehicle sales, a later heavy vehicle V2V rule would reinforce growth in DSRC, especially given the disproportionate number of road-miles driven by trucks.

The model in this report indicates annual rate of adoption of CE/aftermarket equipage will reach nearly two times the growth rate of vehicle installations at its peak. CE/aftermarket will begin to accelerate market penetration of DSRC, bending the adoption curve upward within the first five years following a NHTSA light vehicle V2V rule. The report also suggests that a light vehicle V2V rule would generate momentum in heavy vehicle equipage and V2I, making modest assumptions regarding the timing of investments by heavy vehicle OEMs and road system operators, respectively.

Growth of a future "V2X network" is measured explicitly by the model, and the report shows what percentage of that growth is due to consumer and auto-aftermarket devices. The model structure described in the report implies that a large impetus, such as the adoption of industry-wide standards, is necessary to achieve network effects – economies of scale on both the supply and demand side for DSRC equipment and applications. Overall, the report concludes that growth of CE/aftermarket devices would be a significant economic result of a NHTSA light vehicle V2V rule.

# Value Chain Analysis and Interview Findings

Subsequent to building a market model, the research team conducted a short value chain analysis to identify market participants and to assess their inclination to invest in DSRC equipment or application services. Elements of the value chain were identified so that potential bottleneck issues could be addressed in interviews. (A value chain is the process and network involved with actually gathering components and assembling those components for a product or service.)

The research team identified nearly 100 market participants from a cross-section of automotive, consumer electronics, and infrastructure, and nearly half responded for interviews. Quotes and other replies to open-ended questions were kept anonymous in order to assure candid responses from interviewees. The interviews were for informational purposes only, and were not considered formal or informal comments to NHTSA's ANPRM or other pending government rulemakings or research programs related to DSRC.

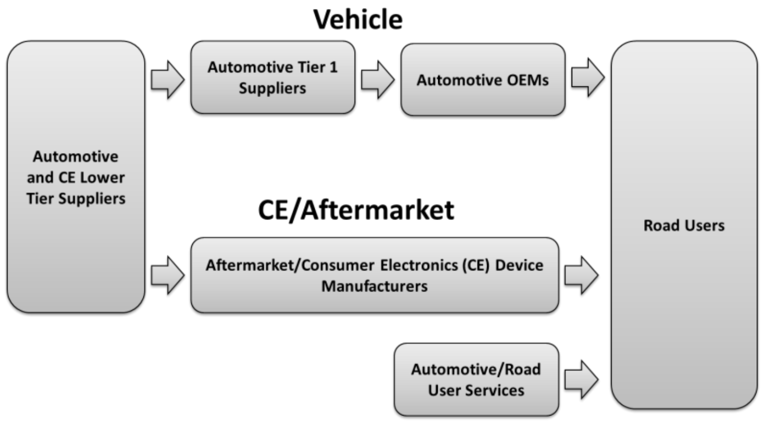


**Figure 1: V2X Value Chain for Road Users (Vehicle and Aftermarket Device/On Board Units) (Source: ITS America)**

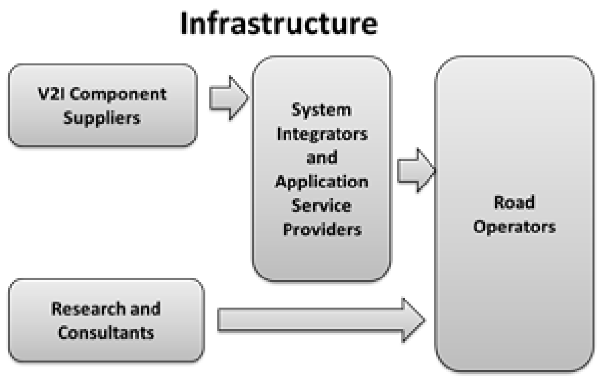


**Figure 2: V2X Value Chain for Road Operators (Source: ITS America)**

The V2V value chain included automotive original equipment manufacturers (OEMs), Tier 1 and 2 suppliers, and consumer electronics manufacturers as shown in Figure 1. Tier 2 suppliers typically also supply other industry sectors, such as other industrial and consumer electronics. The value chain for road operators, or those anticipated to provide road infrastructure services, is included in Figure 2.

Open-ended questions were focused on the following seven areas: market opportunity, supply chain readiness, role of regulation, time to market, product/application development, and aftermarket potential. The following is a summary of the findings for the six major areas of the interviews.

- ***Market Opportunity*** – Most industry participants interviewed were ready to invest in DSRC related products/services (consistent with their business and market focus), but only if a NHTSA V2V rule is anticipated.
- ***Supply Chain Readiness*** – Nearly all suggested that industry is ready to produce equipment, but particular applications were not specified.
- ***Role of Regulation*** – Most respondents believed that a NHTSA rulemaking action would be critical in moving the market, and in some cases suggested that rulemaking was “inevitable.”
- ***Time-to-Market*** – Most suggested time to scale production is one to two years for aftermarket, two to three years for OEM and infrastructure.

- ***Product/Application Development*** – No consensus on any "lead" application that would drive demand, though speculation that one or a "bundle" of lead applications would likely appear.
- ***Aftermarket Potential*** – Most agree on importance, with some Tier 1 suppliers intending to introduce auto-aftermarket products and both Tier 1 and 2s acting as a "coordinator" between the automotive and Consumer electronics (CE)/mobile device ecosystems
- ***Challenges***: Many suggested that more standardization was still required, as well as planning to address hardware obsolescence. V2I deployment will lag with road agencies constrained by budgets, getting value out of DSRC V2X in the first few years with few equipped cars on the road.

*"As V2X gets better defined as the technology matures, retrofit and aftermarket plans will become clearer"*
**Head of V2X Hardware Development for Tier-1 Supplier**

**Automotive Original Equipment Manufacturers**

Despite one automotive OEM's announcement that V2V components will be included in one of their 2017 model year vehicles, other interviewed OEMs suggested that they were waiting for a NHTSA rule before announcing plans to add these DSRC features into their vehicles. Once a potential V2V rule is promulgated, the common sentiment in interviews is that it will take three to four years before new DSRC factory-equipped vehicles would been seen on the roads. The main challenges cited by OEMs were related to marketing – defining value, capturing the public imagination, and gaining acceptance for V2V technology.

**Automotive Tier 1 Suppliers**

The next level of the supply chain, Tier 1 suppliers, offers V2X equipage and application solutions to OEMs. Because they directly work with OEMs, their viewpoint is similar to that of the major automotive companies. All Tier 1 interviewees gave estimates that it will take approximately two to three years after a potential V2V rule for their companies' products to be ready for inclusion in V2X products. A major challenge faced by Tier 1 suppliers is cost, with most interviewees noting that the cost of components will be high until adoption becomes widespread. Most tier one suppliers suggested that size of the market for DSRC depended greatly on whether NHTSA proceeds with its rulemaking.

*"If there is no mandate, this business is going to be very different. There are companies geared for a $5 billion market that would become a $100 million market"*
**Business Development Executive at Tier-1 Auto Supplier**

**Automotive and CE Lower Tier Suppliers**

The final level of the supply chain, Tier 2 suppliers, includes chip makers and software developers of V2X products and applications. Those interviewed noted that chipsets are currently in production and would be ready if a V2V rule were to be enacted. While Tier 2 suppliers are unlikely to be the bottleneck in the vehicle supply chain, they have little direct influence over V2X adoption there. Survey results suggested that Tier 2 suppliers have more influence in the consumer/aftermarket channel, however, and that chipsets and firmware to support DSRC is already available in some cases.

**Aftermarket/Consumer Electronics Manufacturers and Automotive Services**

Interview results from both Tier 1 and Tier 2 suppliers, and Aftermarket/Consumer electronics market participants, suggested that aftermarket products would play a crucial role in wide-scale adoption of DSRC. Many companies within the consumer electronics/device field were interviewed regarding their readiness potential to support DSRC. The common sentiment among potential aftermarket stakeholders is that product deployment will not start until regulation requirements are clear. Most interviewed individuals believed that relying solely on V2V components becoming standard in vehicles will take up to 15 to 20 years, with the shortest estimate being 7 to 10 years. For those who are considering entering the market, aftermarket products could be ready in as little as six months. However, it is important to note that some interviewed companies did not plan on entering this market, citing that OEMs were better equipped to sell aftermarket products.

**Infrastructure System Integrators, V2I Component Suppliers and Others**

As with the V2V value chain, both component and roadside equipment manufacturers said that their companies could be ready to launch products in as little as twelve months. Unlike the V2V value chain, however, the V2I value chain is constrained by more unknown variables, as infrastructure would not be subject to a NHTSA requirement or any other US DOT rule. The inclination of road operators to invest in V2I could not be determined by most industry participants interviewed.

*"There are nearly a dozen major manufacturers of DSRC radios. All the major automakers either have some level of V2X on their premium vehicles or they're working on prototypes"*
**Vice President for Product – A Major US Automaker**

Nearly all market participants interviewed noted that infrastructure DSRC adoption will be the major challenge for overall V2X deployment. However, when addressing the uncertainty surrounding V2I deployment, some interview respondents noted that the use of test pilots would help to gain the confidence of road operators who might be risk-adverse or resource-constrained. Some interview respondents suggested that a consortium of states and Metropolitan Planning Organizations could provide the institutional foundation for establishing and sustaining investment in V2I deployment.

**Table: 1: Summary of Interview Results by Value Chain Category**

| Value Chain Category | Inter-views | Scope | *Market Opportunity?* | *Supply Chain Readiness?* | *Need for Regulation?* | *Time-to-Market?* | *Product/ App Development?* | *Aftermarket Potential ?* | *Challenges?* | *General Sentiment* |
|---|---|---|---|---|---|---|---|---|---|---|
| **Automotive OEM** | 4 | V2X | Yes, 2M vehicles/year without NHTSA rule, several times higher with rule. GM | Yes | Yes, NHTSA rule will drive adoption across OEMs | Three years | Minimal number of applications available from OEMs in beginning | Yes, but requires OEM take the lead in the beginning | None for V2V, Lack of funding for V2I Infrastructure. V2I apps will provide early functionality when vehicle adoption low in the beginning | Very Supportive of DSRC/V2X |
| **Tier 1 Supplier (Automotive Only)** | 11 | V2X | Yes, 1M vehicles/year without NHTSA rule, 17M/year with rule. "$5 billion dollar market if done collectively with OEMs | Yes, when auto OEMs issue RFQ, all Tiers mobilized | Yes, if the approach is consistent (no major changes in standards). Nor rule means it would "flop along" Mandate could also generate economies of scale to reduce cost | 18 months to three years, though app development requires a longer, more complex design approach | Leverage infotainment products to expand into ADAS and V2X. – Automated vehicles may potentially drive demand. For heavy vehicle, platooning would be new app | Some suggest potential, after OEMs begin with new vehicles<br><br>DSRC Modules can share memory and processing power of LTE cellular chipsets. Solutions will be integrated with Bluetooth and WiFi | Potential misalignment of specifications across OEMs (e.g. GPS accuracy), dealing with hardware and software obsolescence, need for high end processors . Need to integrated V2X DSRC with consumer information ("stars on cars rating, or insurance discouts)? | Very Supportive of DSRC/V2X |
| **Lower Tier Suppliers for Automotive and Aftermarket /CE** | 4 | V2X | Yes, 10% of all vehicles in next 6 years | Yes in the beginning, but may have trouble later with high growth. DSRC is on roadmap for all major chipmakers | Yes, without mandate likely no aftermarket. | End-to-end solution by time of mandate –for silicon, 12 to 18 months. | Yes, V2X Integrated with Personal Nav Device (GPS) with mix of features | Working with Aftermarket/CE – potential to integrate ODB-II dongles, DSRC and cellular. | Key gatekeeper is not chipset manufacturers, but those who write the stacks, such as tier 1s. Need standards – innovation is in the software, not chips | Supportive |

| *Value Chain Category* | *Inter-views* | *Scope* | *Market Opportunity?* | *Supply Chain Readiness?* | *Need for Regulation?* | *Time-to-Market? -* | *Product/ App Development?* | *Aftermarket Potential ?* | *Challenges?* | *General Sentiment* |
|---|---|---|---|---|---|---|---|---|---|---|
| **Aftermarket Consumer Electronics** | 11 | V2X | Yes, may take 5-7 years V2X reaches critical mass and before CE devices comes into play | Yes | Yes, no mandate means V2X restricted to OEM luxury car market – but need open standards | Two to Three Years following critical mass | Yes, but still will be an add-on Personal Navigation Devices or other Vehicle aftermarket. May need to design aftermarket products the same time as OEM | Yes more potential than OEM, though some suspect OEM may dominate in the beginning – retrofit solutions available | Standardization may slow, as well as lack of single lead app | Supportive, but have uncertainty about standards |
| **Automotive Services** | 2 | V2X | Yes, but services such as telematics, insurance etc.. will not drive adoption by itself – Long term opportunity only | Yes | Yes, Hindrance to V2X would be "no regulatory movement whatsoever" | | Yes, but as addition to other vehicle data collection (USB dongles for diagnostics/ insurance, feet management systems) | Fleets may want aftermarket solution for safety Return on investment | Security, but may be worked out with gradual deployment | Supportive but see it as very long term opportunity |
| **V2I Component Suppliers** | 5 | V2I | Yes, with some early application | Yes, but require large Traffic Controller OEMs to get involved | | Early applications in 12 months | V2I Signal Priority and Signal Phase & Timing (SPAT) | | Lack of funding for V2I deployment | Supportive, but see V2I ecosystem slow to develop |
| **Systems Integrators and Service Providers** | 2 | V2I | No, No immediate opportunity beyond current USDOT test pilots | | | Two years needed for ecosystem of suppliers to develop. Need P3 or consortium to focus on a few early adopter operators | | | Lack of funding for V2I deployment – hard to scale deployment because of nearly 1000 road operators in US | Supportive, but pessimistic about early adoption of V2I |

| ***Value Chain Category*** | ***Inter-views*** | ***Scope*** | ***Market Opportunity?*** | ***Supply Chain Readiness?*** | ***Need for Regulation?*** | ***Time-to-Market? -*** | ***Product/ App Development?*** | ***Aftermarket Potential ?*** | ***Challenges?*** | ***General Sentiment*** |
|---|---|---|---|---|---|---|---|---|---|---|
| **Research and Consulting** | 4 | V2X | Yes, assuming mandate - but will co-exist with other celluar to support telematics | Yes, supply chain is anticipating rulemaking | Yes, If no mandate, then likely OEMs will split on technology approaches | Estimated 2018-2020 depending on NHTSA rule | LTE Direct may address some apps. DSRC app development is below the radar for larger companies now. “Sometimes, however, ambiguity has been the springboard for certain companies to really dominate.” | Yes, especially with pedestrian mobile devices  Mandate is required to get aftermarket kickstarted | | Supportive, but see complexity in ecosystem development |

# Market Precedents for DSRC

The development and establishment of a mass market mobile ad-hoc communications system for vehicles, with considerable cooperation between public and private sectors, is a feat with few obvious historical or market precedents. In order to build a model, the research team examined past analogous markets, focusing on markets that share some of the unusual characteristics of DSRC and V2X.

To develop a reasonable market model, the research team examined historical growth models of other consumer and industrial electronics such as personal navigation devices (PNDs), satellite radio, advanced driver assistance systems (ADAS), and infotainment systems. These market examples were compared and contrasted to DSRC. The closest market analogy found to a DSRC market model was road user "GPS Navigation" in the consumer electronics space. GPS Navigation occurs in the same distinct market channels as DSRC – vehicle OEM, auto-aftermarket devices (PNDs), and consumer electronics devices such as mobile phones.

> *"The company is developing safety warning systems that will be integrated with our existing products.. our products work with DSRC as well as 4G and LTE applications... Our products are either built into the vehicle or mounted on the dashboard for portability.*
> **Engineering Director for a Navigation Consumer Electronics Manufacturer**

Historically, there is market precedent for new technologies that start in the auto industry to find expanded market presence in consumer electronics. General Motors first offered GPS Navigation in their vehicles in 1995 (i.e. GM's GuideStar system for the Oldsmobile Eighty Eight). Shortly following this move, companies such as TomTom and Garmin saw a steep adoption curve in aftermarket PNDs. Market size in early personal navigation devices doubled annually, until market saturation was reached in 2008. The peak annual global PND sales in the late 2000s represented over 35 million units. However, over the following 2 years, PNDs sold worldwide declined at 15 percent annually. The decline is attributed to the adoption of mobile phone applications with comparable functionality.

PNDs climbed a steep adoption curve from the mid-to-late 2000s. Market size in early personal navigation devices doubled annually, until it saturated in 2008 as shown in figure 3.

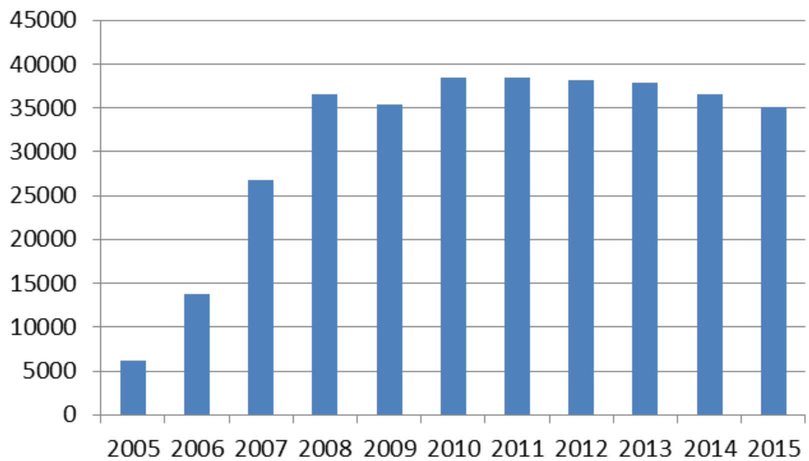


**Figure 3: Historical Global Aftermarket Personal Navigation Devices (PND) from 2005 to 2015 (in 1,000 units) (Source: Statista 2016)**

Road user GPS Navigation is similar to DSRC V2X and other advanced driver assistance technologies in that there are suppliers producing for both vehicle OEM and auto-aftermarket channels. Like DSRC V2X, GPS Navigation also was constrained by low growth in new vehicles sales, so auto-aftermarket channels to existing vehicles represent a growth opportunity. Single function PNDs were later replaced, or co-opted into the more generic consumer electronics category– specifically multi-application mobile computing platforms such as iOS or Android, when GPS chipsets became smaller and less expensive.

Furthermore, the role of government and the establishment of standards may also be analogous to the establishment of the GPS Navigation aftermarket. The GPS Navigation market would not have developed had the federal government (specifically the US Air Force) not established standards for developing civilian user equipment (i.e., GPS Interface Specification IS-GPS-200). Furthermore, two White House directives committed the federal government to support GPS for civilian use, not military only. All of these government efforts signaled to industry a sustained commitment to supporting satellite navigation for commerce and to promote general public acceptance. NHTSA Federal Motor Vehicle Safety Standards for V2V may play a similar role in addressing commercial needs and expanding public acceptance.

*"A hindrance to V2X would be no regulatory movement whatsoever"*
**Chief Strategy Officer of a Tier 1 Supplier**

Where the GPS Navigation analogy fails is the lack of network effects, as one road users' adoption of GPS does not benefit others in a direct way, as is the case with DSRC V2V applications. (One can now argue that later generation "connected' PNDs, that collect traffic data from individual users and disseminate traffic warnings over cellular to others, does introduce network effects, but these effects were limited to traffic apps only and negligible in PND growth). Another limit to the analogy is that early GPS Navigation required dedicated hardware and software and could not leverage general purpose mobile computing platforms (e.g., iOS, Android etc.), like the ones that exist today.

Other auto-centric products and services have similar growth trajectories to GPS Navigation, such as Satellite Radio (e.g. Sirius XM). Satellite Radio achieved 70 percent new vehicle OEM penetration over an extended period. At the same time, Satellite Radio provided equipment and services through other distribution channels such as auto-aftermarket and CE (both dedicated form factors and mobile phone apps). Satellite Radio and GPS Navigation both achieved widespread market penetration in vehicles using multiple market channels. Historically there is market precedent for new technologies to start in the auto industry to find expanded market presence in consumer electronics.

## Description of DSRC Market Adoption Model

From the value chain analysis and interviews, the research team created a simple market model for DSRC equipage. Based on the interview findings, the model was divided into five markets:

- Vehicle OEM
- Aftermarket/Consumer Electronics
- V2X "Ad-hoc" Network
- Infrastructure
- V2X Applications

The purpose of the market model is to simulate Vehicle OEM factory installs and CE/aftermarket growth and to show nearly all DSRC market penetration over time – specifically factoring in a potential NHTSA V2V rulemaking and the existence of aftermarket DSRC devices.

The possibility of a real device/application aftermarket platform was strongly suggested by participants during the interview process. All cited CE/Aftermarket devices would be descendants of current safety prototype devices developed for the US DOT Connected Vehicle Safety Pilot in Ann Arbor, Michigan. Such devices include Aftermarket Safety Devices (ASDs), which are specialized dashboard mounted devices with vehicle systems integration and antenna retrofits (aftermarket grade), and Vehicle Awareness Devices (VADs), which are typically dashboard-mounted with limited or no integration or retrofit (consumer electronics grade). In addition, non-safety aftermarket DSRC devices are currently on the market and already deployed at select sites to support V2I tolling, commercial vehicle credentialing, and other applications.

*"The technologies being deployed in cars, like Wi-Fi and Bluetooth are based on the car becoming a part of the mobile ecosystem. Because DSRC is not tied back to the consumer ecosystem…its pure automobile ecosystem…And with DSRC for it to have any value, it has to be on all cars"*

**Wireless Product Executive for a Semiconductor Manufacturer**

It is likely that DSRC will be piggybacked onto other aftermarket devices platforms such as GPS Navigation, Dash-Cams, Tolling Tags and Fleet Management consoles.  Furthermore, at least one market participant hinted strongly at the ability to port DSRC to mobile phone hardware platforms (e.g., Apple and Samsung) through software upgrades to existing WiFi chipsets in new devices. (DSRC chipsets share similar hardware architecture to Wi-Fi)

Given that device replacement cycles are shorter (typically around 4 years) and vehicle replacement cycles are longer (usually greater than 10 years), the model suggests that aftermarket growth is far less limited by both supply chain and market demand than in the vehicle OEM/factory install only model. As factory installations are limited by low growth in new light passenger vehicles manufactured per year, the model includes a prominent CE/Aftermarket sub-market, which is more diverse and much less constrained in terms of growth potential.

A simple conceptualization of the model is a platform “snowball” as shown in Figure 4 below. A potential Light Vehicle V2V Rule seeds the market place with equipped vehicles, followed by CE/Aftermarket introduction of DSRC for existing vehicles (or other vehicles not subject to the NHTSA V2V rule). This drives application development, specifically growth in V2I applications as road operators begin to deploy. This in turn boosts the size of the V2X network, which increases attractiveness of the V2X platform to application developers.

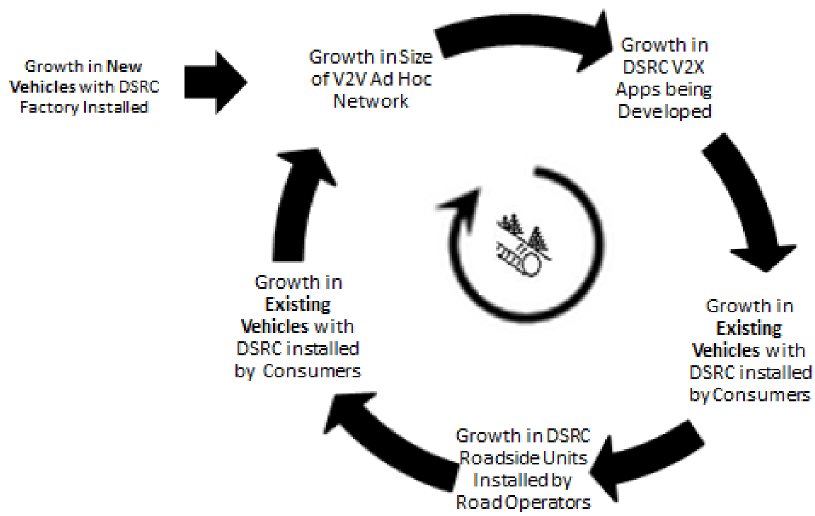


**Figure 4: Simplified Market Adoption Model for DSRC V2X – “Snowball” Effect (Source: ITS America)**

The simple conceptualization in Figure 4 describes a more complicated model, presented below. The market simulation described in this report is based upon the Bass Diffusion model. The Bass Diffusion model consists of a system of simple differential equations that describes the process of how new products get adopted in a population. The model presents a rationale of how current adopters and potential adopters of a new product interact and influence each other. This model was modified to include variables and parameters related to:

- Timing and impact of potential NHTSA Light Vehicle and Heavy V2V Rules;
- Metcalf’s Law, or the network effects related to growth in V2V and V2I networks; and
- V2X application growth over time.

These assumptions were built based upon the results of prior research and interviews conducted by the research team.

### DSRC Adoption Model Structure, Variables and Key Parameters

The DSRC market adoption model consists of a market for all terminal hardware, applications, and network services. There are two OBU markets, one RSU market, and one V2X app market, all connected to one managed “V2X network” of vehicle nodes and infrastructure “roadside” nodes (network service). The model is premised on a potential Light Vehicle V2V Rulemaking with a DSRC equipage mandate sometime after 2016. Key elements are:

1) **Vehicle Market OEM Market** (Original equipment manufacturer DSRC on-board units)
   a) Vehicle OEM – factory installed OBU
      i) Required Installed Light Vehicle (NHTSA Light V2V Rule)
      ii) Required Installed Heavy Vehicles (NHTSA Heavy V2V Rule)
      iii) Voluntary factory installs that occur before NHTSA rulemakings (Light Vehicle only)
2) **Aftermarket/Consumer Electronics Market** (Aftermarket and consumer installed)
      i) Voluntary installs – existing light vehicle
      ii) Voluntary installs – existing heavy vehicle
3) **V2X Ad-Hoc Network** (install base of OBUs and RSUs)
4) **V2X "App" Market** (V2X applications for OBUs and RSUs)
5) **Infrastructure Road Side Unit Market** (DSRC deployed for V2I apps at intersections)

The vehicle OBU market in the model looks at growth (and depletion) of light vehicles and heavy vehicles either manufactured with DSRC (factory-installed), or installed with DSRC devices aftermarket (installed by road users).

**Vehicle OEM and Aftermarket/Consumer Electronics Market**

Given their lifecycle difference and mandate scope, the OBU market consists of two parallel channels: light vehicle and heavy vehicle. In the light vehicle channel, it is assumed that phase-in starts two years after a NHTSA Light Vehicle V2V rule. This assumes a final NHTSA Light Vehicle V2V rule begins implementation in 2019, with the percentage of new light vehicles having DSRC factory-installed being 30 percent, 60 percent, 90 percent, and 100 percent in 2019 to 2022 respectively.

> *"We expect the mandate for commercial vehicles will mirror the ones for light vehicles"*
> **Vice President of a Truck Tier-1 Supplier**

The DSRC market model assumes that a heavy vehicle rule could likely be implemented with a few modifications to the light vehicle rule. (However, combination or articulated trucks will require some additional research period before NHTSA can develop a suitable proposed standard.) A final NHTSA Heavy Vehicle V2V rule would begin implementation in 2020 and require that 100 percent of all heavy vehicles be installed by 2022. Table 1 summarizes these assumptions. The voluntary OEM factory installations apply to any new vehicle that is not subject to the NHTSA Light Vehicle and Heavy V2V rules, which are new vehicles produced before the rule goes into effect.

The *V2X App Market* defines DSRC utility at the application level, and drives adoption of vehicle OEM *voluntary* factory installs and aftermarket equipment sales (*Aftermarket/Consumer Electronics*). The infrastructure RSU deployment also drives voluntary factory installs and aftermarket/CE sales. However, road operator deployment of RSUs is voluntary and would not be subject to a NHTSA V2V rule (*Infrastructure Road Side Unit Market*).

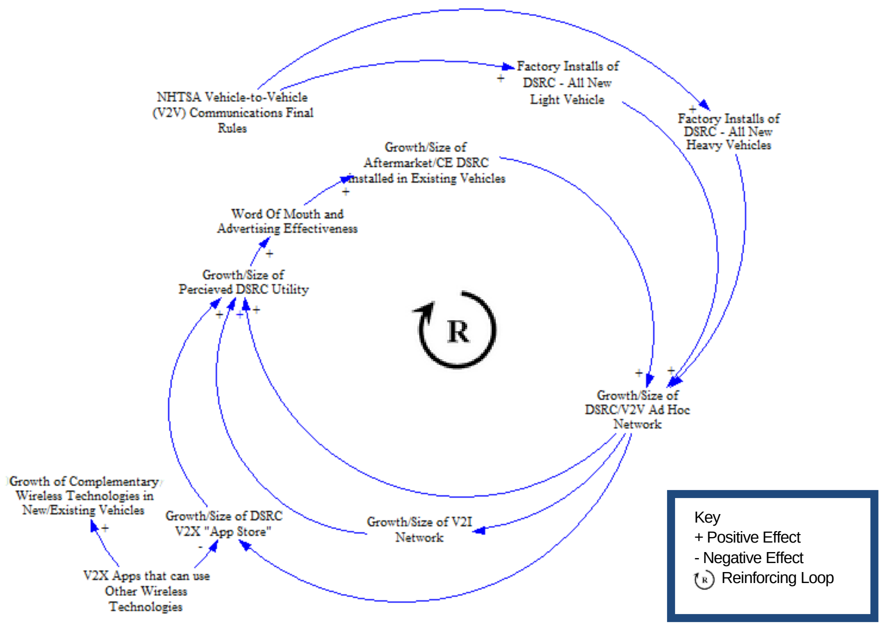


**Figure 5: Expanded Conceptual Market Adoption Model for DSRC V2X (Source: ITS America)**

Figure 5 describes the interaction between the five elements: Vehicle OEM, Aftermarket/Consumer Electronics, V2X Apps, Infrastructure Roadside Unit, and V2X DSRC Ad-hoc Network. Growth in new and light vehicles "gets the ball rolling" and grows the size of the V2V Ad-Hoc network, which increases consumers' perceived utility of DSRC over time. At the same time, growth in the V2V network encourages more development of DSRC-based V2X apps, when in turn grows perceived utility. Apps that can leverage other wireless technologies (e.g. cellular, satellite etc.) are filtered out to remove their effect on the growth of DSRC equipage.

A conventional Bass Model using a "word of mouth" marketing variable takes into account the contacts between all vehicle DSRC users with DSRC OBUs and RSUs and "non-users." Word of mouth established that a certain percentage of non-users will adopt DSRC once they have made contact with those who have adopted. The model takes into account advertising effectiveness, to measure the impact from advertisement to convert DSRC non-users to choose to install DSRC. All these parameters are chosen to simulate a modest aftermarket adoption. Additionally, the model takes into account the fact that older vehicle are scrapped, with a vehicle "survival probability" decaying exponentially over any given vehicle's age.

**Table 2: Market Adoption Model Assumptions**

| Key Model Element | Description | Source/Notes | Relevant DSRC/V2X Market | Key Model Variables/ Parameters (see Appendix B) |
|---|---|---|---|---|
| **"Light Vehicle"** | Vehicles with a gross vehicle weight rating less than 10,000 pounds | Source: NHTSA ANPRM | Vehicle Market OEM (Factory installed OBU) | • "light vehicles being manufactured without DSRC"<br>• "light vehicles installing DSRC" (Aftermarket/CE)<br>• "light vehicles being manufactured with DSRC" (OEM) |
| **"Heavy Vehicle"** | Vehicles with a gross vehicle weight rating greater than 10,000 pounds | Source: NHTSA ANPRM | Vehicle Market OEM | • "heavy vehicles being manufactured without DSRC"<br>• "heavy vehicles installing DSRC" (Aftermarket/CE)<br>• "heavy vehicles being manufactured with DSRC" (OEM) |
| **Number of Registered Vehicles (All "Existing Vehicles")** | 234,000,000 Light<br>11,000,000 Heavy | Source: Federal Highway Administration Statistics, 2011 | Aftermarket Consumer Electronics (Aftermarket or Consumer Installed OBU) | • "light/heavy vehicles without DSRC" |
| **New Vehicle Annual Sales Factory OEM** | 15,000,000 Light<br>729,000 Heavy | Source: International Organization of Motor Vehicle Manufacturers | Vehicle Market OEM | • "light/heavy vehicle monthly sales" |
| **Vehicle Life Span** | 15.6 years Light<br>15.1 years Heavy | Source: Based on the number of registered vehicles and their annual US sales | Vehicle Market OEM<br><br>AND<br><br>Aftermarket/Consumer Electronics | • "light/heavy vehicles without DSRC depletion"<br>• "light/heavy vehicles with DSRC depletion" |
| **Factory Installs of DSRC – New Light and Heavy Vehicle** | 30% Annual US Vehicle Sales in 2019, 60% in 2020, 90% in 2021, 100% in 2022 for Light Vehicle<br><br>For heavy vehicles 0% in 2021, 100% in 2022 of annual sales | Source: NHTSA ANPRM Assumed NHTSA OEM Factory Installed DSRC Equipage Requirement Phase-In for New Vehicles | Vehicle Market OEM | • "mandated DSRC ratio on …light/heavy vehicles"<br>• "light/heavy.. "..vehicles manufactured with DSRC" |
| **Pre-NHTSA V2V** | 10,000 Light vehicles | Source: General Motors | Vehicle Market OEM | • "known light |

| Key Model Element | Description | Source/Notes | Relevant DSRC/V2X Market | Key Model Variables/ Parameters (see Appendix B) |
|---|---|---|---|---|
| **Rule OEM Factory Equipage** | | | | vehicle production manufactured with DSRC" |
| **Initial Number of V2X Apps** | 5 current apps | Source: NHTSA - ANPRM Current apps completed by the Crash Avoidance Metrics Partnership (CAMP) | V2X Application Market | • "Initial number of apps" |
| **Growth/Size of V2X "App Store"** | Number of V2X Applications To- Be-Developed<br><br>70 new apps developed over ten years<br><br>Short term: 6 apps in three years<br>Medium term: 51 in three to five years<br>Long term: 13in six years and beyond | Source: Connected Vehicle Reference Architecture (CVRIA) with app development timeframe described in more detail in Appendix A | V2X Application Market | • "potential apps" Smoothed piecewise linear function based on the number of applications sorted by term |
| **Urban Vehicle Miles Traveled (Urban VMT)** | Average VMT of vehicles in the urban areas =7,789/mo light<br>=12,756 heavy | See Appendix: Used as proxy to determine Growth/Size of V2V network | V2X "Ad-Hoc" Network (Network Services) | • "average urban VMT light vehicles"<br>• "average urban VMT heavy vehicle"<br>• OBU equipped VMT |
| **Growth/Size of V2V Network** | (OBU equipped VMT/total VMT)^2<br><br>Note: VMT = Urban Vehicle Miles Traveled | Metcalfs Law, modified to reflect transient connectivity between DSRC equipped vehicles. Ratio of Equipped VMT over total VMT all squared is used, counting only urban miles traveled, where most vehicle-vehicle and vehicle-intersection interactions and potential V2X connections occur | V2X "Ad-Hoc" Network | • "v2v network potential"<br>• "equipped VMT"<br>• "total VMT" |

| Key Model Element | Description | Source/Notes | Relevant DSRC/V2X Market | Key Model Variables/ Parameters (see Appendix B) |
|---|---|---|---|---|
| **Growth/Size of V2I Network** | Assumes growth of 300,000 sites in 9 years<br><br>V2I growth only begins after an "infrastructure investment kickoff threshold" met – where 40% of VMT is OBU equipped. | Model assumes that road operators will delay investment until significant numbers of vehicles are equipped | V2X "Ad-Hoc" Network | • "Infrastructure improvement rate"<br>• "infrastructure investment kickoff threshold"<br>• "equipped VMT" |
| **Growth/Size Perceived DSRC "Utility"** | A function of growth of apps and size of V2V and V2I networks. Perception is a smoothed time delay function that reflects inertia in consumer understanding of true utility | For simplification, all V2X apps, V2I nodes and V2V nodes equally contribute to DSRC utility | Combination of All Markets:<br><br>Vehicle OEM<br>Aftermarket/CE<br>V2X Apps<br>V2X Network Services | • "potential apps utility"<br>• "v2v network potential"<br>• "infrastructure concentration"<br>• "DSRC utility"<br>• "time delay"<br>• "Perceived Utilities" |
| **Word of Mouth and Advertising Effectiveness** | A function of perceived DSRC Utility (V2X applications), "word-of-mouth" (WOM) conversions taking into consideration contact rate between non-adopters and adopters, plus advertising effectiveness | Initial contact rate between aftermarket/CE adopters and non-adopters is 5 contacts/vehicle per month. WOM Conversion rate of these monthly contacts is 3%/mo. Advertising Effectiveness is 1e-005/mo. | Combination of All Markets:<br><br>Vehicle OEM<br>Aftermarket/CE<br>V2X Apps<br>V2X Network Services | • "contact rate"<br>• "perceived utilities"<br>• "DSRC utility"<br>• "ideal adoption fraction"<br>• "contacts between DSRC users and non-users"<br>• "potential vehicle concentration"<br>• "Ideal adoption fraction" |
| **Growth/Size of Aftermarket/CE DSRC installed in Existing Vehicles** | Consumers installing DSRC on-board units in Light/Heavy Vehicles | For simplification, no distinction is made between aftermarket installations and consumer installed CE. | Aftermarket/Consumer Electronics | • "light/heavy... vehicles installing DSRC" (aftermarket/CE) |

### V2X Ad-hoc Network

The *V2X "Ad-Hoc" Network* is a composite of the *Vehicle OEM, Aftermarket/Consumer Electronics* (On-Board Units), and *Infrastructure Roadside Units* markets. The largest network effects, specifically the number of DSRC nodes (all communicating vehicles and roadside units) are modeled explicitly.

*Network Utility* is a weighted sum of DSRC-based *V2V Utility* and *V2I Utility*. *V2V Utility* represents perceived utility from the DSRC-based vehicular ad-hoc network, and *V2I Utility* signifies the impact of the infrastructure network deployed at signalized intersections. It is assumed that total DSRC total utility (*DSRC Utility*) is the product of potential DSRC applications utility (*App Utility*) and DSRC network utility (*Network Utility*) as follows:

*DSRC Utility = Ad-Hoc Network Utility (Composite of V2V and V2I) * App Utility*

Growth in the size of the DSRC V2V ad-hoc network*, or V2V network potential,* is the square of the ratio of *equipped VMT* to *total VMT* as follows:

$$\left(\frac{Equipped\ VMT}{Total\ VMT}\right)^2$$

According to Metcalfe's Law, the value of a telecommunications network is proportional to the square of total number of connected nodes. Metcalf's law is suited for evaluating networks with a fixed number of always connected nodes (i.e. nodes that connected all times with a relatively fixed topology). As a result of this, the square of the market adoption percentage was used to quantify *V2V Utility* to accommodate the ad-hoc topology. It aligns with the observation that the chance for two DSRC-equipped vehicles to encounter each other is roughly the square of DSRC on-vehicle equipage penetration.

*"We believe DSRC is one of the key enablers for future safety and driver support systems"*
**General Manager of a Japanese Automaker**

*V2I Utility* is measured by the total number of *DSRC Infrastructure Concentration*, an output from the DSRC RSU Submarket model discussed below. *Infrastructure Concentration* describes the market adoption of RSUs. Figure 4 describes how V2V and V2I combine, along with potential app utility, to drive total DSRC utility. The formulas that define parameters and variables in the market adoption model are documented in Table 1, with the completed model provided in Appendix B.

Figure 5 illustrates the model and describes how network and app growth drives market adoption through reinforcing feedback – Growth in New equipped vehicles drives Growth in V2V Network, which drives growth in both V2I and V2X, all driving consumers perceived utility of DSRC, which finally drives aftermarket adoption.

**Infrastructure Roadside Unit Market**

The *Infrastructure Roadside Unit Market* is dependent upon the deployment of OBUs, both factory installed OEM and consumer installed Aftermarket/CE. DSRC RSU sites are expected to be deployed in a variety of settings within the roadway infrastructure, including at signalized and non-signalized intersections, ramp meters, or other locations with high incidence of crashes. Traffic control devices such as traffic signals, ramp meters, and dynamic message signs may use DSRC RSUs to mediate between vehicles at critical locations where vehicle-vehicle conflicts might occur, or where road geometry or other static or dynamic road conditions may require safety-critical advisories to drivers. Other locations may include tolling gantries and way stations where existing infrastructure can be leveraged and those services require vehicle point of presence. (e.g., tollway entry or commercial vehicle weight and inspection).

According to interviews and existing research, the deployment of V2I applications falls into three broad categories: crash avoidance, real-time traffic management, and signal prioritization. (Individual applications in these categories are addressed in Appendix A.) Road and other infrastructure operators often must go to great lengths to justify deployment along several lines:

- **V2I Crash Avoidance Applications:** Generally, crash avoidance V2I apps require the low-latency features of DSRC and would need to be justified by road operators based upon concrete safety needs and potential benefits. However, given low rates of DSRC equipage in the beginning, road operators may not see enough benefits early in the deployment phase, in the form of numbers of averted crashes, and therefore could not justify investment until more vehicles were equipped with DSRC.

- **Real-Time Adaptive Traffic Management Applications:** Highly automated traffic control, such as real-time adaptive signal systems, often requires extensive detection systems, particularly on arterials. (Examples include LAACTS, ACS-Lite, InSync, SCATS, and SCOOT, which are deployed at less than 5% of intersections.) Road operators generally deploy cameras, loop detectors or even radar sensors, and the cost of detection and complexity are significant enough to stunt the demand for these more advanced traffic control systems. DSRC V2I can typically provide broader detection and classification (for both vehicle types and vehicle movements) capability and can therefore provide a less complex, less expensive and more capable alternative to legacy adaptive systems. However, DSRC V2I real-time traffic management also requires medium to high vehicle DSRC equipage rates.

- **Real-Time Prioritization for Fleet and Special Vehicles:** Vehicles such as police cars, fire trucks, ambulances, and transit vehicles may have priority at intersections. Some specially credentialed freight vehicles or special category vehicles (e.g. current alternative fuel vehicles, or future registered or experimental “high level” automated vehicles) may also get priority as well at intersections, highway on-ramps, or way-stations. Real-time signal prioritization applications are not constrained by market penetration of vehicle OBUs, since only a few emergency and other vehicles require DSRC equipage. As in the case of Real-Time Adaptive Traffic Management Applications, these V2I apps would represent only a limited percentage of all intersection deployments.

Typically many of these applications that are fielded today are stand-alone, proprietary, end-to-end solutions, lacking standardization not just in the communications layer, but at the application layer as well. From the interviews, several respondents suggested that open standards build upon DSRC will make it easier to create solutions from different vendors, potentially lowering the cost of V2I and providing cost-effective paths to upgrade equipment and expand applications.

Since DSRC supports multiple applications, bundling Crash Avoidance, Adaptive Traffic Management, and Signal Prioritization services on a DSRC V2I platform together would likely lower total cost of ownership for these services, and may even reduce maintenance costs through the retirement of much less capable legacy systems such as traffic detectors (such as cameras, radars, loop detectors, legacy transponders, etc.). One example is of a multi-app V2I system package is the *Multi-Modal Intelligent Traffic Signal System (MMITSS)* developed by the University of Arizona/University of California-Berkeley, Arizona DOT/Maricopa County DOT, and a handful of RSU and Traffic Controller OEMs. Given that the DSRC V2V suite standardizes the interface and application messaging sets for vehicle data, other efforts to standardize data sets from traffic control devices will gain added momentum. A V2I hardware and application ecosystem may then operate alongside one for V2V, but will grow only after investment in DSRC roadside units by infrastructure operators. (See appendix A for further details).

Given that there is not readily-available information to predict the number of potential DSRC roadside unit sites, the outlook for RSU deployment is less obvious than for vehicle OBUs. At a minimum, the size of RSU footprint will likely correspond at a minimum with the number of traffic control devices, most of which are at signalized intersections. The American Association of State Highway and Transportation Officials (AASHTO) identified in their *Infrastructure Footprint Analysis* that of the 300,000 intersections, 200,000 are set to be upgraded with advanced traffic controllers. The cost to replace 200,000 legacy signal controllers was estimated to be between $352.6M to $443.6M. When these traffic signal controllers are replaced, they will likely be replaced with hardware that is compatible with DSRC RSUs and V2I apps at a minimum.

The *Infrastructure Roadside Unit Market* portion of the market adoption model correlates signalized intersections (300,000) to the number of RSU sites, as a conservative estimate of the total market for RSUs. This reduces the scope of *Infrastructure Roadside Unit Market*, even though V2I deployments may also include other locations besides signalized intersections. These potential “additional” V2I sites are ignored in this report to maintain a conservative estimate of V2I RSU deployment and to reduce the number of unique parameters that drive “network utility” in the market adoption model (See section addressing *V2X “Ad-hoc Network”* for a summary of DSRC Utility and network effects).

The market adoption model makes two additional critical assumptions related to timing. First, it assumes a delayed start to investment in V2I RSU deployment. Second, when broader scale investment in V2I (investment beyond the past and current pilot deployments) does start, a low rate of growth in RSUs deployed in road infrastructure is assumed. Delays and low growth rate in RSUs in the market adoption model are recommended because of the following:

- **Drawn-out Planning and Investment Cycles for Traffic Management Infrastructure:** Investments in infrastructure are generally “lumpy,” where resources are budgeted for large projects on a less-frequent basis over extended periods of time. Results from interviews, and those reported in the AASHTO Infrastructure Footprint Analysis, suggest that as legacy traffic controllers are replaced with new controllers, those new controllers will include RSUs, bundled with some V2I applications (i.e. adaptive signal control, signal priority, etc. described earlier and in Appendix A).

- **Threshold Level of DSRC Equipage in Vehicles to Support V2I Apps:** Some V2I applications require at least medium level percentages of vehicle DSRC adoption (40-60%) before benefits of V2I for road operators can be recognized. At those minimum vehicle penetration rates, road operators would begin to see benefit from data collection from DSRC equipped vehicles to support their current and future operations at intersections. Therefore road agencies may wait until V2V DSRC equipage in light and heavy vehicles progresses to a certain level before adding V2I RSU equipment to all their intersections. (It should be noted again that real-time signal priority applications for special fleet vehicles [e.g. Ambulance, Fire, Transit] do not require high levels of DSRC vehicle and are ideal for early V2I deployment.)

- **Inertia in Adoption of New Technology in Infrastructure:** Furthermore, according to interview findings, road operators were determined to be largely risk averse and resource constrained, with investment cycles that span decades rather than years. Interviews with would-be V2I system integrators and application service providers suggested that public agencies did not currently have the technical resources and expertise to deploy V2I now, and that it would take some time before those could be put in place. Interviews with system integrators suggested that past and current "pilot deployments" would likely grow road operator experience, expertise and comfort with V2I systems.

These elements suggest that the market adoption model reflect considerable delays in the growth of an *Infrastructure Roadside Unit Market*. Given the uncertainties of V2I, the market adoption model treats V2I as exogenous, and parameterizes delay in V2I deployment to assume no dramatic growth in road infrastructure investment overall during the first several years following a NHTSA rulemaking (i.e., no special federal or multi-state program to expedite investment in RSU V2I deployment, with no equivalent USDOT requirement for V2I as is currently being contemplated by NHTSA for V2V) This is done to ensure that V2I deployment, which would likely greatly incentivize V2V aftermarket equipage in vehicles, could not be unintentionally overestimated in the V2V market adoption model.

Delays by road operators in deploying RSUs are therefore parameterized explicitly. This is done to separate the effect of factory installations and aftermarket growth of OBUs (the V2V Network effect) directly resulting from the potential NTHSA V2V rule, from the effects of infrastructure, which are not subject to the NHTSA proposed rules. RSU deployment includes key variables of *Number of DSRC RSU Site* (number DSRC installed sites with maximum total at 300,000 intersections) and *DSRC Infrastructure Concentration (*DSRC installed sites/total infrastructure sites). (See table 1 and Appendix B for definitions of these and the following "Infrastructure" parameters)

An *Infrastructure Improvement Threshold* is set at 40 percent. This "threshold" means the adoption model assumes road operators will wait until nearly 40 percent of all road user miles driven are driven with vehicles equipped with DSRC. (i.e., *DSRC Equipped VMT*) before deploying V2I RSUs. This reflects fact that road agencies may wait until there is medium level vehicle penetration before beginning investments in RSUs.  (See earlier discussion, table 1 and Appendix B for definitions of these parameters)

After the threshold is crossed, steady V2I RSU deployment is contemplated. A total of 300,000 intersection sites are upgraded with DSRC RSUs over one decade. The *Infrastructure Improvement Rate* parameter is defined as 300,000 roadside unit (RSU) sites in 9 years. The infrastructure improvement rate reflects a steady investment profile and does not assume any accelerated Federal or State level programs to deploy V2I.

The *Infrastructure Roadside Unit Market* lags the *Vehicle OEM Market* by a number of years following a NHTSA V2V rule. The market adoption model recognizes that investment in V2I will increase the utility of DSRC for road users, and would therefore drive further growth in V2V through the aftermarket/CE channel. However, given the complexity of V2I deployment and the long capital replacement cycles, the network growth effect from V2I RSU equipage is muted.

### V2X Application Market

DSRC as a platform can support multiple applications, and the *V2X Application Market* portion of the model computes the total road users and operators' perceived value of DSRC applications that affect OEM and aftermarket DSRC equipage adoption. This perceived value, measured by *Growth/Size Perceived DSRC "Utility"*, is the product of DSRC application utility (*App Utility*) and DSRC network utility (*Network Utility*). *App Utility* grows with the size of the DSRC "app store" or app ecosystem.

Here, *App Utility* is the sum of the individual applications' utility, which is set identical for all DSRC applications under deployment or in concept. The identical utility level is based upon the prevailing wisdom, surfaced in interviews, that there is no known single app or so-called "killer app" which encompasses significant utility to predominantly drive DSRC adoption by itself.

The NHTSA Advanced Notice of Proposed Rulemaking identified five V2V applications that had been developed by a consortium of automakers (the Crash Avoidance Metrics Partnership, or CAMP). Beyond these initial V2V applications, there are a number of additional applications that are in concept of operations or standards development. A total of 121 V2X applications were identified from USDOT ITS Joint Program Office research and the *Connected Vehicle Reference Implementation Architecture (CVRIA)*. These applications are in various stages of market and technical maturity, with some applications in prototype, development, or conceptual stages. Some of these applications may be supported by other wireless technologies besides DSRC. (All applications may be found in Appendix A of this report)

All 121 V2X applications were evaluated by three "market and technical" criteria:

- Immediacy of Benefits
- Perceived Value by End Users
- Deployment Complexity

*Immediacy of Benefits* and perceived value to end users are subjective, but rankings are approximate for the purposes of forecasting model. Criteria and rankings are addressed in Appendix B. *Deployment Complexity* is less subjective. *Deployment Complexity* is sub-divided by *Stakeholder/Ecosystem Size* (number of cooperating groups needed for market introduction), *Maturity of Application* and *Other Messaging Standards*, and *General Technical Complexity*. A composite rating for each application was generated, with applications ranked by overall market and technical maturity. Again, these market and technical rankings are only for the purposes of establishing a rough estimate for maturity and a more detailed analysis would be necessary to assess any given application.

This market and technical maturity was then translated into the following time frames: 0-3 years, 3-5 years, 6-10 years, and beyond 10 years. For any given application, once benefits and perceived value become clear, and technical issues resolved, an application's development cycle is assumed to include a year from concept to implementation, and another six months to be tested. Sixty percent of tested applications are approved, and the disapproved applications are redeveloped and retested. It should be noted that assumptions regarding timeframes for application introduction are only rough estimates for the purpose of forecasting and do not reflect all past or ongoing work on V2X applications.

Of the 121 V2X applications, 51 of them were determined to be wireless technology "agnostic." Agnosticism indicates that the application could use a number of different complementary wireless technologies, if available either embedded or otherwise integrated into the vehicle. These applications could use DSRC if available, but could also use other radio access technologies such as satellite or cellular, if available. The test for wireless "agnosticism" is not an in-depth analysis, and precise assessment of particular applications would likely require further study. Wireless technologies that are not inherently complementary with DSRC (i.e. other short range wireless systems etc.) are addressed in the section "*Special Note about DSRC V2X Market Adoption and Other Wireless Technologies*.")

Based on the readiness of DSRC V2X applications, the remaining 70 applications are categorized into four timeframes. Applying the technology and market criteria and ratings, and filtering out applications that can use complementary wireless systems provide a rough distribution of V2X applications over time, as shown in Table 7.

By eliminating a third of the 121 applications, and addressing market and technology maturity, the platform/ecosystem effect estimated here is conservative and therefore reasonable for the purposes of forecasting. These V2X applications and their deployment timing are described in detail in Appendix A.

**Table 3: Estimated DSRC V2X Application Deployment Categories and Timeframes**

| Market And Technical Maturity Timeframe | Number of DSRC only V2X Applications | Expected Time to begin Development Following Light V2V Rule |
|---|---|---|
| Current | 5 | Before V2V Rule |
| 1 (Highest) | 6 | 0-3 Years |
| 2 | 51 | 3-5 Years |
| 3 | 5 | 6-10 Years |
| 4 (Lowest) | 8 | 10+ Years |

It should be noted that all V2I applications are ranked level two or later, which reflects the complexity of RSU deployment as discussed in the previous section. Although rankings are in some sense subjective, interviews with stakeholders suggested that one key element is *Stakeholder/Ecosystem Size. Stakeholder/Ecosystem Size* is high for infrastructure projects, which are not mass-produced or benefit from economies of scale or scope, as in vehicle or aftermarket/CE markets.

Infrastructure V2I applications are more complex and require cooperation from not just technology producers and end users, but also cooperation and outreach among multiple public sector agencies, regulators, road users, and even the general public. Integrating with existing technology infrastructure is also a challenge. This complexity was suggested in interviews with systems integrators and other firms that provide architecture and engineering (A&E) services to infrastructure operators and agencies.

Lastly, for each application, its app utility is assumed to undergo logarithmic growth over time – fast growth in the application's initial introduction, followed by gradually slower growth, until utility reaches a flat plateau. This utility growth curve captures the gradual performance improvement due to software iteration. Both parameters describing growth in apps and utility per app simulates, albeit indirectly and implicitly, the network (platform) effect of equipage driving growth in apps, and apps driving growth in equipage.

# Forecast of DSRC Market Adoption in Vehicles

The following five figures show the model forecast results. Figure 6 depicts the baseline growth forecast of on-road vehicles equipped with DSRC over time (as a percent of total vehicle population). The blue (light vehicle) and red (heavy vehicle) curves are the baseline and shows the adoption level of factory-installed DSRC devices alone which are the result of the NHTSA rules. (Please note that horizontal axis dates in all the figure graphs are to the left of the year).

The green (light vehicle) and grey (heavy vehicle) curves show total DSRC equipage when installation of aftermarket/CE devices is also included. Figure 6 illustrates that the aftermarket/CE is a significant factor in accelerating DSRC adoption by road users. Aftermarket/CE DSRC growth in existing vehicles is largely driven by the “network effects” that result in the growth in V2V factory installed equipage in new vehicles.

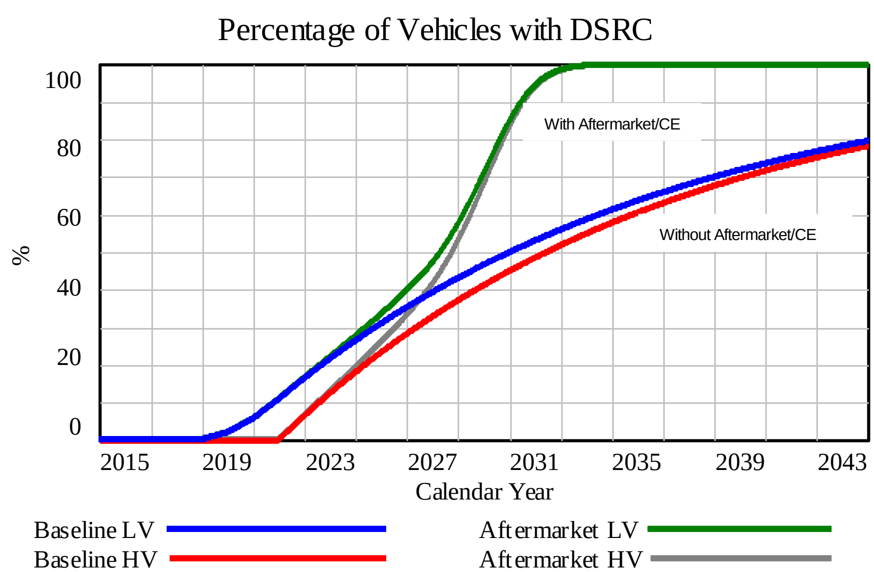


**Figure 6: Forecast Percentage of Road Users (All Light [LV] and Heavy [HV] Vehicles) Equipped with DSRC 2015-2045 (Source: ITS America)**

As shown in Figure 6, the implication is that aftermarket shows tremendous growth potential. This growth is built from the results of a potential NHTSA V2V rule requiring that all new passenger vehicles be installed with DSRC.

The effect of aftermarket installations is displayed when the two curves diverge, when 30 percent of vehicles have DSRC. This result reflects conservative assumptions regarding the weight of V2V network effects (Metcalfe’s Law or *V2V Network Potential*) and rollout of V2X applications. Heavier weighting of V2V network effects and faster rollout of applications would likely bend the adoption curve further upward. Figure 6 shows that with the inclusion of aftermarket/consumer electronics V2V capable devices, the timeframe for having V2V in 80% of light vehicles (green) is reduced by approximately fifteen years, when compared to the baseline (red).

Growth rates between "factory installed" DSRC and Aftermarket/CE is also telling. Figure 7 (a) and (b) illustrates the monthly factory (vehicle OEM) and aftermarket DSRC installs for both light and heavy vehicles. The blue curves represent factory installations that follow the assumed mandate ratio for NHTSA V2V rules on light and heavy vehicles. The adoption of vehicle OEM factory installs drives the aftermarket installations gradually, as the red curves show.

Figure 7 (a) shows Aftermarket/CE devices are the fastest growing category of DSRC V2X by 2028 in the light vehicle market. The growth of the DSRC V2V aftermarket/CE accelerates to double the rate of vehicle OEM sales by 2030. Similar pattern applies to heavy vehicle market (see Figure 7b) (Please note that the vertical axis in these figure graphs is growth in vehicles/month in the thousands)

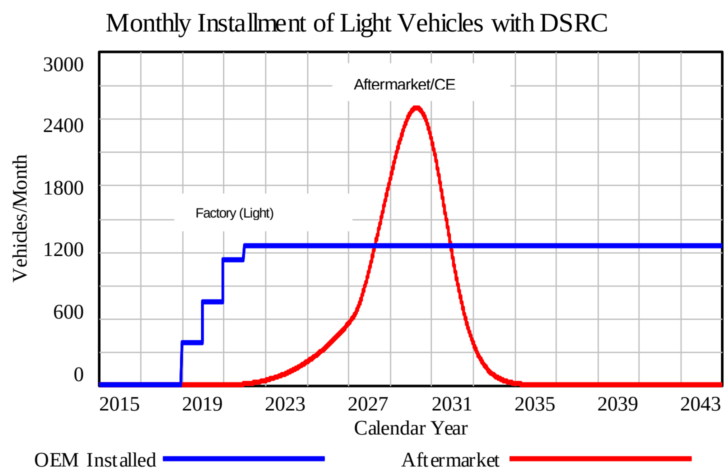


**Figure 7a: Forecast Monthly Rate of Factory and Aftermarket Installs (Light Vehicles) in Thousands (000) (Source: ITS America)**

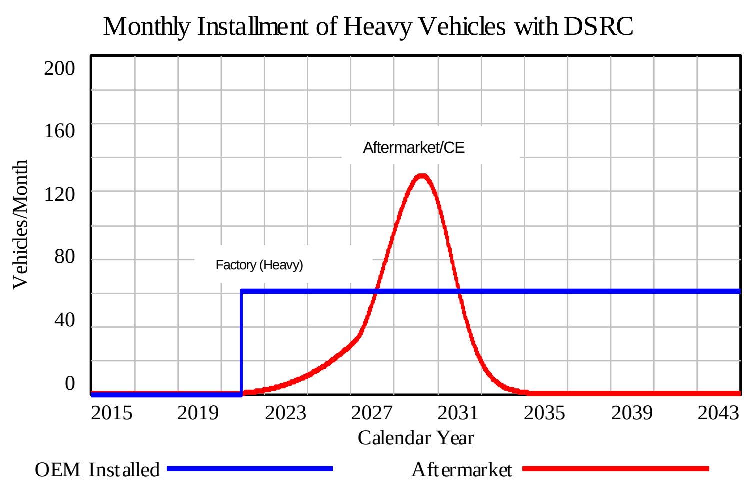


**Figure 7b: Forecast Monthly Rate of Factory and Aftermarket Installs (Heavy Vehicles) in Thousands (000) (Source: ITS America)**

The growth in DSRC Aftermarket/CE peaks about 10 years after the potential V2V rule. Following the peak, the majority of vehicles will be equipped with DSRC – either because older vehicles have been replaced with new vehicles, or because older vehicles that have not been replaced have installed an aftermarket DSRC device. As a result, aftermarket installs will thereafter diminish as the current national fleet of registered vehicles turns over.

Figure 8 shows the absolute numbers of vehicles equipped with DSRC for both the light and heavy vehicle categories. Again, blue represents vehicle OEM factory installs, while the red curves show the size of the Aftermarket/CE. (Please note that horizontal axis dates in all the figure graphs are to the left of the year, and "vehicles" are in thousands).
By 2029, ten years after the V2V rule, 60% or a cumulative 146 million cars will have DSRC/V2X equipment either as a NHTSA V2V standard in newly manufactured light and heavy vehicles, or as an aftermarket/consumer electronics feature for existing vehicles.

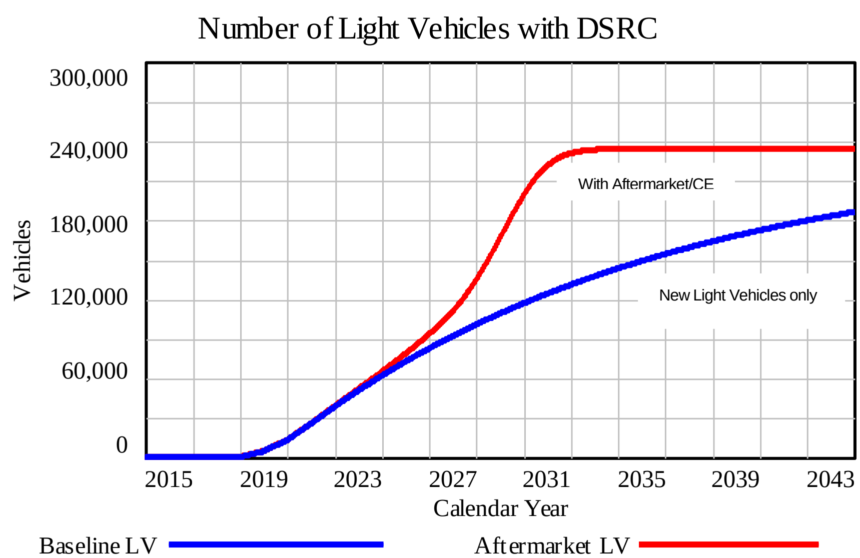


**Figure 8a: Forecast Number of Vehicles with DSRC (Light Vehicles) in thousands(000) (Source: ITS America)**

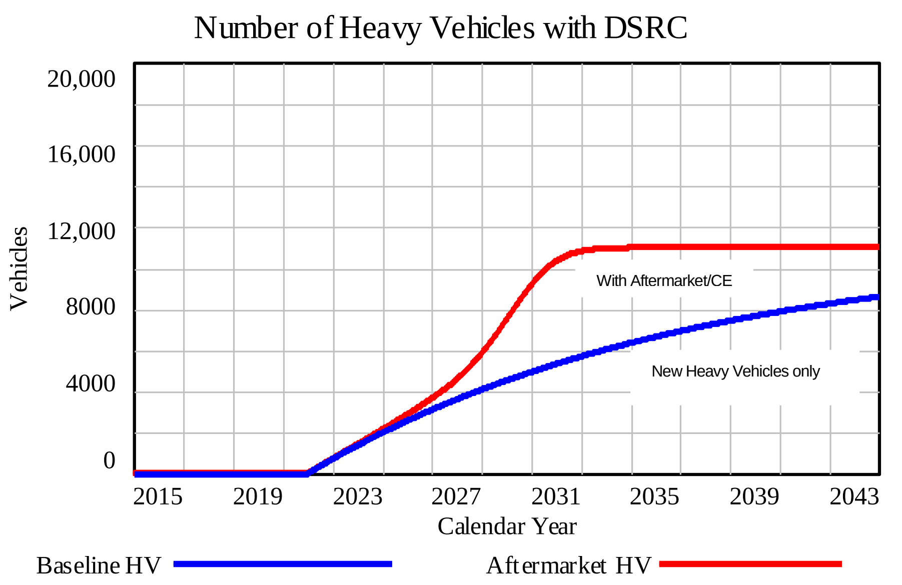


**Figure 8b: Forecast Number of Vehicles with DSRC (Heavy Vehicles) in thousands (000) (Source: ITS America)**

## Special Note about DSRC V2X Market Adoption and other Wireless Technologies

The V2X Application Market described was limited to DSRC-only applications. Applications that were not strictly "point-of-presence," or because of less stringent requirements could rely on other telecommunications media besides DSRC, were removed are not considered in the market adoption model.

The term point of presence (PoP) in telecommunications is an artificial demarcation point or interface point between communicating entities in telecom, but is used here to represent a place where a vehicle and other highway element meet. Point-of-presence applications are ones where a vehicle must "present" itself at a specific location such as an intersection, an on-ramp, or a facility gantry, in order for some form of real-time direction/control, security authentication/validation, or some other processing to occur. (Another term of art is "proximity aware" applications) An example is when a vehicle appears at an intersection or ramp and is stopped by a traffic light, or appears at a tolling gantry or way-station to be processed for entry onto a highway.

> *"…DSRC module can share memory and processing power of the cellular chipsets…we know how to merge all of these technologies to be efficient in total cost of ownership…"*
> **Chief Product Officer for Mid Tier Supplier (all sectors)**

Out of all 121 identified applications, 50 were found that could be, in concept, supported by other complementary telecommunications media besides DSRC, making the additional assumption that other media would be ubiquitous in nearly all new and existing vehicles (see previous section on V2X App Market for further discussion and Appendix B). Currently, the most ubiquitous wireless system in embedded in vehicles is still AM/FM radio. Highway authorities rely AM/FM primarily because of it prevalence in vehicles to provide critical warnings about weather or other road conditions that are dangerous. (e.g. road signs and dynamic message signs will often instruct drivers to tune into Highway Advisory Radio for information during critical events). Although AM/FM has been the lowest common denominator service for road users for decades, cell phones have likely already supplanted it. Other vehicle-embedded wireless services are arriving and will also likely supplant brought-in mobile devices.

Other wireless technologies and networks such as cellular (Fourth Generation [4G] LTE Advanced), Wi-Fi (commercial versions of 802.11 in addition to DSRC 802.11p), and Bluetooth are likely to be commonly available and integrated in vehicles to support mass-market applications such traffic/weather, infotainment/internet access, navigation, and other vehicle services such as diagnostics, fleet management, and logistics. These technologies will either be installed at the factory by OEMs (embedded), or will rely on mobile devices brought into the car being integrated (rich interface between car and consumer electronics) or tethered (basic functions such as hands free calling).

Cellular, like DSRC, will grow in both aftermarket consumer electronics and in vehicle OEM channels. Other embedded wireless technologies support specific functions such Tire Pressure Monitoring Systems, Wireless Keyless Entry, and in the future, wireless Controller Area Networks. SBD estimates that embedded cellular will reach 110 million of 300 million vehicles by 2025, around the same that that DSRC Aftermarket/CE market begins to accelerate according the market adoption model.

Other radio access technologies and networks such as cellular can, in theory, support limited vehicle-to-vehicle communications. Many services such as traffic information utilize this approach, in which data is collected by vehicles (location and speed polled from fleet management systems in trucks, or OEM telematics), processed centrally, and multi-cast to subscribed users. Traffic data is typically only polled in long intervals (minutes or hours), or is event-driven (traffic incident alerts).

*"OEMs are almost starting to listen that they have to have upgradable modules in the car.*

**Executive Vice President for a wireless mid-tier supplier**

However, cellular systems likely would not be able to accommodate the transmission of data that is streamed – sent on a constant basis – at intervals required by a number of V2V and V2I applications. DSRC-based safety applications must transmit every 10-100 milliseconds. If such messages were to be transmitted over cellular, each message would add "signaling" overhead. Signaling is metadata to setup and tear down connections, as well as address translation, authentication, mobility, billing, and other networking services. Such "signaling surges" in cellular systems occurs when applications are unaware of the network load or the status of other applications, and poll excessively at the expense of other applications and network resources. Uncoordinated connection requests and lots of signaling create a "network brownout" or signaling surge.

Cellular networks are typically architected and designed for fewer, longer communications sessions point-to-point rather than many shorter polling events. Next-generation cellular architectures seek to minimize network overhead, if for no other reason than to reduce cost per megabyte and improve scalability. However, since wireless carriers have little control over applications, and are unable to regulate device behavior, carriers must use "traffic analysis" to model traffic and provide a best estimate of resources needed for any given time of day. Attempts to “shape” or restrict traffic to devices is complicated from both a technical and regulatory perspective.

A cellular network could also collect and rebroadcast all safety messages to and from all vehicles in a cell region (cell regions can be up to 40 square kilometers), but this would mean a given vehicle would be getting messages from all vehicles in the region, not just those that are a short distance away. Furthermore, cellular networks are designed to serve point-to-point or multi-casting (one-to-many) over wide areas, but find geo-casting difficult. Geo-casting is a specialized multicasting technique for mobile systems, where messages are multicast to mobile nodes within a given geographical region. In order to replicate the way in which DSRC broadcasts safety messages to neighboring vehicles, a cell network would need to associate each vehicle with not just a mobile network address, but a very small region moving around each vehicle. An application service provider would need to match multiple regions and “points of presence” (i.e. neighboring vehicles, or even vehicles speeding toward each other) and pass messages between them. The additional “geo-routing” would likely add latency and overhead to the communications, as well as require management of a large centralized database of vehicle location information to route safety messages.

> *“LTE Direct will have significantly lower latency than 4G LTE… If there is a [DSRC V2V] mandate, everybody will have a market opportunity. If there’s no mandate, I still think some of the OEMs will try to differentiate based upon similar technologies.*
> **Strategy Executive in the Wireless Industry**

Furthermore, such a large database would be a tempting target for hackers. Storage of such data collected centrally would also likely raise privacy concerns and potentially force consumers to trade privacy for safety. DSRC relies on limiting communication to only neighboring vehicles, with no central database collecting information, and using anonymization techniques between neighboring vehicles to thwart tracking. In addition, the auto industry and road operators developed a set of privacy principles to provide guidance to designers of V2X applications to ensure there is no personally identifiable information released.

The closest “point of presence” or “proximity” application service provider that uses cellular architecture that can be compared DSRC V2V safety apps in terms of signaling would be geo-located instant messages services, such as Yik Yak. The Yik Yak app polls users in a 10 mile radius of each other for messages, and allows users in that 10 mile radius to anonymously post notes – virtual graffiti. Users within a 6 km radius are constantly polled; however, the number of users per square kilometer (tens of users) is limited and the frequency of communication (all users in the radius estimated one per second) is such that it would not represent a signaling burden to a given cell tower (cell towers on average cover 20-40Km radius).

> *“DSRC is a special type of protocol that allows for very short and very fast transmissions of information in 20 to 50 milliseconds…A built in cellular phone in a car that would talk to a server and then back to the vehicle would introduce delay of a couple of seconds. That’s why people are pushing for DSRC because this is critical and real time.”*
> **Head of Product Management for a Tier-1 Supplier**

Incidentally, future “highly current, highly local” applications with “more, shorter sessions” such as Yik Yak are likely the kind of application use cases that are driving other short range ad-hoc, peer-to-peer wireless technologies that are in their infancy, such as LTE Direct.

New peer-to-peer technologies in the same broad category DSRC, such as LTE-Direct or Low Energy Bluetooth, may be embedded in the vehicle to allow for ad-hoc pairing of mobile devices to vehicle head units for hands-free telephony and messaging. Although Bluetooth is currently used by some road operators to detect vehicles and to calculate speed of traffic flows (speed is derived from detectors that passively detect Bluetooth signatures in phones where drivers are using their phones in hands-free mode), no other use of these is known for Intelligent Transportation Services or inter-vehicle networking. LTE Direct and Bluetooth, however, do not provide the power and range to support V2X application services. LTE Direct provides 500 m support and Low Energy Bluetooth 100 m support, while DSRC provides a range of 1000 m.

LTE Direct is currently in standardization in 3GPP as release 12 (current release as of this publication is 10). It is a device-to-device platform using licensed spectrum to create a wireless carrier platform for autonomous discovery of proximity applications. Applications described include people discovery (social networking), push advertising, geo-fencing, and autonomous check-ins for gaming and vendor services. Release 12 specs were frozen in March of 2015, so equipment may be available in several years. Apple is also developing a competing service using unlicensed spectrum (Low energy Bluetooth) for their iOS platform.

The following four communication requirements are the most important considerations for V2X applications:

1) *Connection Setup and Communications Latency* – Reduced overhead from setting up communications (signaling) as well as reduced communication latency, which is the sum of signal propagation delay, transmission delay, and queuing delay.
2) *Communication Range* – Communication range is the maximum distance from the sender that the packet can be decoded by the receiver.
3) *Privacy Protection* – The Vehicle Infrastructure Integration Consortium (VIIC) defined the level of privacy protection needed for V2X as end-to-end communication with no collection of any personally-identifying information at any time in connection with bootstrapping or provision of security services or mandatory applications.
4) *Broadcasting Mode and Point-of-Presence* – Broadcasting is a method of transferring a message to all recipients simultaneously in close geographic proximity.

In terms of scalability and latency, particularly for V2V safety applications, DSRC is preferable to infrastructure-based telecommunication methods such as cellular because its peer-to-peer approach does not require a “middleman” or a cloud-based brokering service to support geo-casting. In contrast, many V2I applications are more tolerant of latency and do not necessarily require broadcasting mode. For such V2I applications, where privacy protection is not as critical a requirement, communication range likely determines the viability of other media.

More importantly, other peer-to-peer technologies suffer from limited range or limited scalability. LTE Direct suffers the same latency and scalability issues as its LTE Advanced, requiring cell base stations to mediate communications. (LTE Direct must use base stations to coordinate spectrum use between P2P users and conventional mobile users, which adds signaling overhead and potentially connection or communications delay.) Furthermore, geographical and market coverage for LTE Direct is not guaranteed, as not all wireless carriers might support it as a feature of LTE Release 12, or may support it, but in only select geographical areas.

Because geographical and market coverage is not guaranteed, there is risk adoption will be diffuse from a standards perspective, raising costs and introducing complexity. It will make V2V (and more broadly V2X) standardization across vehicles and mobile devices far more complicated by requiring support of multiple standards, as was the case in early cellular (CMDA vs. GSM) or even in the tolling transponder market (at one point, least 10 standards across tolling authorities in the US). Multiple wireless standards may make V2X application development and provisioning of services more complicated as well as developers will need to accommodate multiple wireless technologies and other communications infrastructure.

Low Power Bluetooth's maximum communication range is about 100 meters, which may allow support for higher latency applications, such as border management systems and automated toll/user fee collection and administration, which require only very short-range communications while vehicles slow down or are stopped at gates or gantries. (This may not be the case for tolled freeways or commercial waystations where vehicles are traveling at or hear highway speeds.)

In the interviews, some respondents suggested the auto industry should wait for so-called Fifth Generation radio networks/technologies (5G) before deploying V2V. However, no commercially available products or even standards to support crash avoidance or driving automation features are likely to be ready in the time frame suggested by the NHTSA ANPRM. The conclusion drawn was that potential dampening of DSRC uptake from the competition of other radio access technologies could happen, but that the progress on supporting safety critical V2X applications was too indefinite and uncertain to allow for explicit treatment in the market model. 3GPP LTE Release 14 cellular V2X requirements were developed in September 2016. However, Release 14 has completed to fully evaluate scope of V2X application support, to include crash avoidance.

# Limitations of the Market Adoption Model

Due to time and scope constraints, there are areas of research that could not be included in this final report. Fortunately, the model developed for this study can be adapted to explore other market variables. (The model equations are included in Appendix B) The following areas represent additional research opportunities:

- **Scenario Looking at Acceleration of Infrastructure Deployment –** Responses from most market participants who were interviewed suggested that greater V2I deployment will likely drive up vehicle DSRC adoption. A future area of research could be to manipulate the rates of infrastructure deployment. For example, an accelerated program to deploy V2I could be modeled to determine the impact of RSU infrastructure on CE/Aftermarket adoption for vehicles.

- **Expand the Definition of the V2I Application Market** – The current model assumes only V2I applications suited to signalized intersections and is limited to RSU equipage at signalized intersections in urban areas. However, it is likely that other existing roadway infrastructure such as ramp meters, dynamic message signs, tolling locations, or other traffic control devices (e.g. stop signs at un-signalized intersections or warning signs at dangerous roadway curves, etc.) would also support V2I applications. There would also be a number of private sector V2I applications operated by organizations that interact with the driving public. Examples could be repair shops, car dealerships, parking facilities, departments of motor vehicles, and public establishments that utilize drive-through lanes. An area of future research could be to model how an increase in the number of infrastructure sites beyond signalized intersections in urban areas would change the overall adoption of DSRC devices.

- **Further Distinguish Differences between V2X Applications** – The current report makes a simplifying assumption – that there will be at least a combined 51 applications for both V2V and V2I over the next 15 years, and that any single application has the same utility as any other (see the discussion of the "killer application" earlier). However, it is likely that the applications would carry varying weights of utility depending on their purpose. A future area of research could be to create separate and more detailed utility models for V2V and V2I applications. These models can adjust individual application utility with the growth of market penetration. Creating two models would help to distinguish how each group of applications affects the adoption of DSRC.

- **The Addition of Handheld Mobile Devices for Vehicle-to-Pedestrian (V2P) –** There are nearly as many pedestrians and cyclists as there are registered light and heavy vehicles. However, these are not addressed in the DSRC Market Adoption model. This is unfortunate because these are vulnerable road users, and would have disproportionately higher utility for DSRC, especially in reference to safety. (Motorcyclists, even though there are fewer of them than pedestrians and cyclists, are also classified as vulnerable road users and would also greatly benefit from DSRC.) Current V2X apps that support pedestrians have been developed and given the potential opportunity for handheld mobile app devices to serve as DSRC units in the future, modeling the impact of this larger population of road users would significantly change the market adoption estimates.

> *"There are small niche players that have created small unique applications that are very successful companies. When you'll have V2V, V2I and V2X, there will be all sorts of niche players…"*
> **Executive Vice President of a Tier 1 Supplier**

# Conclusion

This project sought to understand the practical impact of a potential NHTSA Light and Heavy Vehicle V2V Rule addressing vehicle-to-vehicle communications on the growth the consumer electronics/auto aftermarket category of DSRC-enabled devices. This was accomplished through a series of industry interviews with the various stakeholders involved in the auto, consumer electronics, road infrastructure equipment and service sectors.

Results from interviews and study of analogous markets were combined to create a market adoption model. This model generated a forecast measuring the growth of DSRC products in the aftermarket consumer electronics domain.

The forecast generated suggests that by 2029, seven years after a Light Vehicle V2V mandate phase-in period is completed, 60% of vehicles, or a cumulative 146 million cars, will have DSRC/V2X equipment. This DSRC/V2X equipage will be either a direct result of a NHTSA V2V standard in newly manufactured light and heavy vehicles, or of the availability of aftermarket/consumer electronics devices for all categories of existing vehicles (see Figure 9).

The model suggests that aftermarket/consumer electronics adoption will begin to accelerate market penetration of DSRC in all vehicles. This acceleration will occur within just four years following a NHTSA Light Vehicle V2V Rule, when the rule requires 100% of new production vehicles to be equipped with V2V technology.

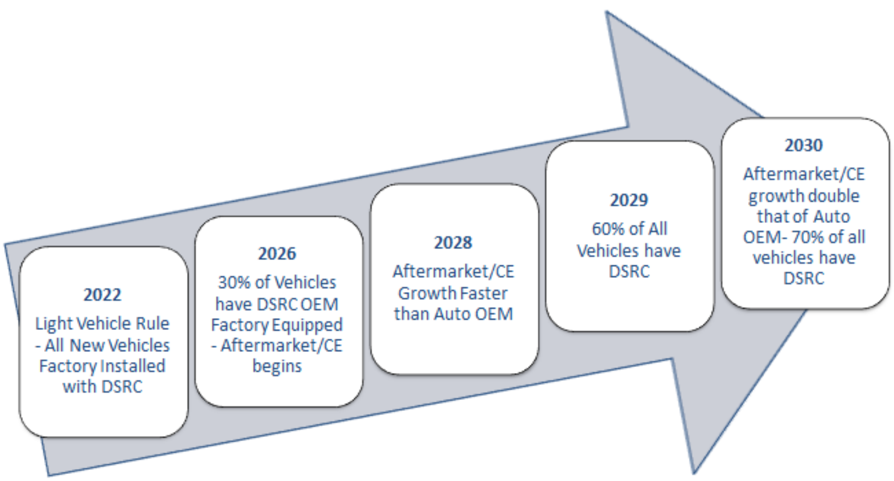


**Figure 9: Major Forecasted Automotive and Aftermarket/CE Milestones – DSRC Market Adoption Model (Source: ITS America)**

Aftermarket/consumer electronics devices are the fastest growing category of DSRC V2X by 2028 in the light vehicle market. The growth rate of aftermarket/ consumer electronics DSRC equipage will be nearly double that of OEM factory installations when it reaches its peak in 2030.

These model results are consistent with interviews with executives in the consumer electronics space. Conventional thinking among some in this group suggested 5-7 years for V2X to reach critical mass and for CE devices come into play.

Model results and interviews match with historical patterns for roughly analogous products, suggesting that adoption in the aftermarket consumer electronics channel is not instantaneous. It took a little over a decade between when GPS navigation was first introduced as optional vehicle equipment in the 1990s, to when the market for aftermarket dashboard personal navigation devices became saturated. It took a few more years still before GPS navigation became part of the mobile "app phone" ecosystem.

> *"Long term, with autonomous vehicles, there's going to be a fundamental need for cars to talk to each other,"*
> **Wireless Product Executive at Semiconductor Manufacturer**

It is likely that DSRC will transition from the automotive domain to the broader mobile ecosystem. Given the similarities between DSRC and WiFi hardware , DSRC might piggyback on any device that is also WiFi enabled. DSRC might be integrated into GPS personal navigation devices, dash-cams, tolling tags, as well as into mobile phones. The market adoption model does not assign economic values to its forecasts; however, results from the model suggest that DSRC V2X could be a future island of growth in the larger $200 billion consumer electronics marketplace.

# Appendices

## Appendix A: V2X Application Market

*App Utility* is the sum of the individual applications' utility, which is set identical for all DSRC applications under deployment or in concept. The identical utility level is based upon the prevailing wisdom, surfaced in interviews, that there is no known single app or "killer app" which encompasses significant utility to predominantly drive DSRC adoption by itself.

All 121 V2X applications were evaluated by three market and technology criteria:

- Immediacy of Benefits
- Perceived Value by End Users
- Deployment Complexity

Immediacy of benefits and perceived value to end users is subjective, but rankings are addressed in Appendix B. Deployment complexity is less so. Deployment complexity is sub-divided by *Stakeholder/Ecosystem Size* (number of cooperating groups needed for market introduction), *Maturity of Application* and *Other Messaging Standards*, and *General Technical Complexity*. A composite rating for each application was generated, with application ranked by overall market and technical maturity.

The following describes how applications are rated, with lower numbers indicating more favorable conditions for early rather than later market introduction.

A: Immediacy of Benefits:

- Near term (3-5 years after initial deployment) = 1
- Medium term (5-10 years) = 2
- Long term (beyond 10 years) = 3

B: Perceived Value by End Users:

- High = 1
- Medium = 2
- Low = 3

C: Deployment Complexity: Number of Cooperating Groups Required for Market Introduction

- One additional organization = 1
- Two additional organizations = 2
- Three or more additional organizations = 3

D: Deployment Complexity: Maturity of Application and Other Messaging Standards

- Supporting message set approved by SDO = 0
- No supporting message set approved by SDO = 1

E: Deployment Complexity: General Technical Complexity

- No additional hardware and only minor software required = 0
- Additional hardware and/or major software required = 1

| A | B | C | D | E | Score | Timeframe |
|---|---|---|---|---|---|---|
| **IMMEDIACY OF BENEFITS** - | **PERCIEVED VALUE TO END USER** | **DEPLOYMENT COMPLEXITY - STAKEHOLDER/ ECO-SYSTEM SIZE** | **DEPLOYMENT COMPLEXITY – STANDARDS** | **DEPLOYMENT COMPLEXITY - GENERAL TECHNICAL** | **COMPOSITE SCORE** 'Immediacy of Benefits x Perceived Value by End Users x Deployment Complexity '=A*B*(C+D+E) | Ranked and Distributed in four timeframes –(1) 0-3 years, (2) 3-5 years, (3) 6-10 years, and (4) beyond 10 years |

**Table 4: Criteria and Scoring for V2X Applications**

Applications were rated based upon the results of interviews reviewing market opportunity ("Immediacy of Benefits," "Perceived Value to End Users," and "Deployment Complexity/Stakeholder Size") and literature review of standards ("Deployment Complexity/Standards and General Technical Complexity"). Although these ratings are subjective, they provide a rough estimate of technical and market maturity for various V2X applications. These rough estimates are translated into estimates for growth of the number of V2X application over time.

This market and technical maturity was then translated into timeframes: 0-3 years, 3-5 years, 6-10 years, and beyond 10 years. For any given application, once benefits and perceived value become clear, and technical issues resolved, an application's development cycle is assumed to include a year from concept to implementation, and another six months to be tested.

Of the 121 V2X applications, 51 of them were determined to be wireless technology "agnostic." Agnosticism indicates that the application could use a number of different wireless technologies, if available as either embedded or otherwise integrated into the vehicle. These applications could use DSRC, but could also use other radio access technologies such as Wi-Fi or cellular, if available. These applications were excluded from V2X application growth in the model.

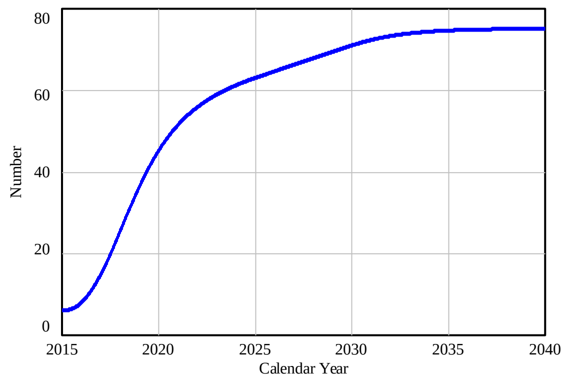


**Figure 10: Number and Schedule of DSRC V2X Applications (smoothened by exponential function) (Source: ITS America)**

It should be noted that the growth and magnitude of "network effect" of V2V equipage likely has a positive and delayed effect over growth in the V2X apps ecosystem. In other words, as the number of vehicles expands, incentives to develop, test and deploy particular apps will grow. This positive effect in the model (see appendix B) is ignored for the purpose of simplification.

Applying the technology and market criteria and ratings, and filtering out applications that can use other wireless systems to provide a rough distribution of V2X applications over time for the purpose of estimating market adoption. It is not an in-depth analysis, and precise assessment of particular applications would likely require further study.

## Table 5 Rough Estimation of Market/Technical Maturity for V2X Applications

| V2X APPLICATION | IMMEDIACY OF BENEFITS | PERCIEVED VALUE TO END USER | DEPLOY-MENT COMPLEXITY - STAKEHOLDER/ ECO-SYSTEM SIZE | DEPLOY-MENT COMPLEXITY - STANDARDS | DEPLOY-MENT COMPLEXITY - GENERAL TECHNICAL | COMPOSITE SCORE | END USER | POINT OF PRESCENCE (Proximity Aware) | WIRELESS AGNOSTIC | TIMEFRAME ASSESS-MENT |
|---|---|---|---|---|---|---|---|---|---|---|
| Emergency Electronic Brake Light | 1 | 1 | 1 | 0 | 0 | 1 | General Road User | Y | | 1 |
| Control Loss Warning | 1 | 1 | 1 | 0 | 1 | 2 | General Road User | Y | | 1 |
| Emergency Vehicle Alert | 1 | 1 | 2 | 0 | 0 | 2 | General Road User | Y | | 1 |
| Intersection Movement Assist | 2 | 1 | 1 | 0 | 0 | 2 | General Road User | Y | | 1 |
| Red Light Violation Warning | 1 | 1 | 2 | 0 | 0 | 2 | General Road User | Y | | 1 |
| Situational Awareness | 1 | 1 | 1 | 0 | 1 | 2 | General Road User | Y | | 1 |
| Commercial Vehicle Vehicle Roadside Operations | 1 | 1 | 2 | 0 | 1 | 3 | Commercial Vehicle | Y | | 2 |
| Eco-Freight Signal Priority | 1 | 1 | 2 | 1 | 0 | 3 | Commercial Vehicle | Y | | 2 |
| E-Screening / Virtual Weigh Station (DSRC) | 1 | 1 | 2 | 0 | 1 | 3 | Commercial Vehicle | Y | | 2 |
| Freight Signal Priority (FSP) | 1 | 1 | 2 | 1 | 0 | 3 | Commercial Vehicle | Y | | 2 |
| Truck Safety Condition Monitoring and Reporting | 1 | 1 | 2 | 0 | 1 | 3 | Commercial Vehicle | Y | | 2 |
| Wireless Roadside Inspection (DSRC) | 1 | 1 | 2 | 0 | 1 | 3 | Commercial Vehicle | Y | | 2 |
| Emergency Vehicle Preemption | 1 | 1 | 3 | 0 | 0 | 3 | Emergency Responders | Y | | 2 |
| Emergency Vehicle Priority | 1 | 1 | 3 | 0 | 0 | 3 | Emergency Responders | Y | | 2 |
| Blind Spot Warning + Lane Change Warning | 3 | 1 | 1 | 0 | 0 | 3 | General Road User | Y | | 2 |
| Do Not Pass Warning | 3 | 1 | 1 | 0 | 0 | 3 | General Road User | Y | | 2 |
| Driver Gap Assist at Signalized Intersections | 1 | 1 | 2 | 0 | 1 | 3 | General Road User | Y | | 2 |
| Commercial Vehicle Roadside Operations | 1 | 1 | 2 | 0 | 1 | 3 | Road Operators | Y | | 2 |
| E-Screening / Virtual Weigh Station (DSRC) | 1 | 1 | 2 | 0 | 1 | 3 | Road Operators | Y | | 2 |

| V2X APPLICATION | IMMEDIACY OF BENEFITS | PERCIEVED VALUE TO END USER | DEPLOY-MENT COMPLEXITY - STAKEHOLDER/ ECO-SYSTEM SIZE | DEPLOY-MENT COMPLEXITY - STANDARDS | DEPLOY-MENT COMPLEXITY - GENERAL TECHNICAL | COMPOSITE SCORE | END USER | POINT OF PRESCENCE (Proximity Aware) | WIRELESS AGNOSTIC | TIMEFRAME ASSESS-MENT |
|---|---|---|---|---|---|---|---|---|---|---|
| Truck Safety Condition Monitoring and Reporting | 1 | 1 | 2 | 0 | 1 | 3 | Road Operators | Yes | | 2 |
| Wireless Roadside Inspection (DSRC) | 1 | 1 | 2 | 0 | 1 | 3 | Road Operators | Yes | | 2 |
| Vehicle Turning Right in Front of a Transit Vehicle | 3 | 1 | 1 | 0 | 0 | 3 | Transit | Yes | | 2 |
| Probe-enabled Traffic Monitoring (DSRC) | 1 | 1 | 2 | 0 | 1 | 3 | Road Operators | | Yes | 2 |
| Border Management Systems | 1 | 1 | 3 | 0 | 1 | 4 | Commercial Vehicle | Yes | | 2 |
| Freight Drayage Optimization | 1 | 1 | 2 | 1 | 1 | 4 | Commercial Vehicle | | | 2 |
| Curve Speed Warning | 1 | 1 | 2 | 1 | 1 | 4 | General Road User | Yes | | 2 |
| Electric Charging Stations Management | 1 | 1 | 2 | 1 | 1 | 4 | General Road User | Yes | | 2 |
| Integrated Multi-Modal Electronic Payment | 1 | 1 | 2 | 1 | 1 | 4 | General Road User | Yes | | 2 |
| Intelligent Traffic Signal System (I-SIG) | 1 | 1 | 2 | 1 | 1 | 4 | General Road User | Yes | | 2 |
| Pedestrian in Signalized Crosswalk Warning | 1 | 1 | 3 | 0 | 1 | 4 | General Road User | Yes | | 2 |
| Pre-crash Actions | 2 | 1 | 1 | 0 | 1 | 4 | General Road User | Yes | | 2 |
| Railroad Crossing Warning | 1 | 1 | 3 | 0 | 1 | 4 | General Road User | Yes | | 2 |
| Receive Parking Space Availability and Service Information | 1 | 1 | 2 | 1 | 1 | 4 | General Road User | | | 2 |
| Signal Phase and Timing | 1 | 2 | 1 | 0 | 1 | 4 | General Road User | Yes | | 2 |
| Stop Sign Gap Assist | 1 | 1 | 2 | 1 | 1 | 4 | General Road User | Yes | | 2 |
| Warnings about Upcoming Work Zone | 1 | 1 | 2 | 1 | 1 | 4 | General Road User | Yes | | 2 |
| Border Management Systems | 1 | 1 | 3 | 0 | 1 | 4 | Road Operators | Yes | | 2 |
| Integrated Multi-Modal Electronic Payment | 1 | 1 | 2 | 1 | 1 | 4 | Road Operators | Yes | | 2 |
| Intelligent Traffic Signal System (I-SIG) | 1 | 1 | 2 | 1 | 1 | 4 | Road Operators | Yes | | 2 |
| Vehicle classification-based Traffic Studies (DSRC) | 1 | 2 | 2 | 0 | 0 | 4 | Road Operators | Yes | | 2 |

| V2X APPLICATION | IMMEDIACY OF BENEFITS | PERCIEVED VALUE TO END USER | DEPLOY-MENT COMPLEXITY - STAKEHOLDER/ ECO-SYSTEM SIZE | DEPLOY-MENT COMPLEXITY - STANDARDS | DEPLOY-MENT COMPLEXITY - GENERAL TECHNICAL | COMPOSITE SCORE | END USER | POINT OF PRESCENCE (Proximity Aware) | WIRELESS AGNOSTIC | TIMEFRAME ASSESS-MENT |
|---|---|---|---|---|---|---|---|---|---|---|
| Container/Chassis Operating Data | 1 | 1 | 2 | 1 | 1 | 4 | Commercial Vehicle | | Yes | 2 |
| Oversize Vehicle Warning | 1 | 1 | 2 | 1 | 1 | 4 | Commercial Vehicle | Yes | Yes | 2 |
| Smart Truck Parking (DSRC) | 1 | 1 | 2 | 1 | 1 | 4 | Commercial Vehicle | | Yes | 2 |
| Advanced Traveler Information Systems (ATIS) | 1 | 1 | 2 | 1 | 1 | 4 | General Road User | | Yes | 2 |
| Eco-Smart Parking | 1 | 1 | 2 | 1 | 1 | 4 | General Road User | | Yes | 2 |
| Motorist Advisories and Warnings (DSRC) | 1 | 1 | 2 | 1 | 1 | 4 | General Road User | | Yes | 2 |
| Queue Warning (Q-WARN) (DSRC) | 1 | 1 | 2 | 1 | 1 | 4 | General Road User | | Yes | 2 |
| Stop Sign Violation Warning | 1 | 1 | 2 | 1 | 1 | 4 | General Road User | Yes | Yes | 2 |
| Traveler Information- Smart Parking | 1 | 1 | 2 | 1 | 1 | 4 | General Road User | | Yes | 2 |
| CV-enabled Traffic Model Baselining & Predictive Traffic Studies (DSRC) | 1 | 2 | 2 | 0 | 0 | 4 | Road Operators | | Yes | 2 |
| Performance Monitoring and Planning | 1 | 2 | 2 | 0 | 0 | 4 | Road Operators | | Yes | 2 |
| Road Weather Information for Maintenance and Fleet Management System | 1 | 1 | 2 | 1 | 1 | 4 | Road Operators | | Yes | 2 |
| Vehicle Data for Traffic Operations | 1 | 2 | 2 | 0 | 0 | 4 | Road Operators | | Yes | 2 |
| Eco-Transit Signal Priority | 1 | 1 | 3 | 1 | 0 | 4 | Transit | Yes | | 2 |
| Transit Signal Priority (TSP) | 1 | 1 | 3 | 1 | 0 | 4 | Transit | Yes | | 2 |
| High-occupancy Toll Lanes (DSRC) | 1 | 1 | 3 | 1 | 1 | 5 | General Road User | Yes | | 2 |
| Pre-Clearance, Expedited Screening of Cars and Trucks | 1 | 1 | 3 | 1 | 1 | 5 | General Road User | Yes | | 2 |
| Freight -Specific Dynamic Travel Planning | 1 | 1 | 3 | 1 | 1 | 5 | Commercial Vehicle | | Yes | 2 |
| Incident Scene Pre-Arrival Staging Guidance for Emergency Responders | 1 | 1 | 3 | 1 | 1 | 5 | Emergency Responders | | Yes | 2 |
| Dynamic Route Guidance (F-DRG) (DSRC) | 1 | 1 | 3 | 1 | 1 | 5 | General Road User | | Yes | 2 |
| Pedestrian Mobility | 1 | 1 | 3 | 1 | 1 | 5 | Pedestrians | Yes | | 2 |

| V2X APPLICATION | IMMEDIACY OF BENEFITS | PERCIEVED VALUE TO END USER | DEPLOY-MENT COMPLEXITY - STAKEHOLDER/ ECO-SYSTEM SIZE | DEPLOY-MENT COMPLEXITY - STANDARDS | DEPLOY-MENT COMPLEXITY - GENERAL TECHNICAL | COMPOSITE SCORE | END USER | POINT OF PRESCENCE (Proximity Aware) | WIRELESS AGNOSTIC | TIMEFRAME ASSESS-MENT |
|---|---|---|---|---|---|---|---|---|---|---|
| Incident Scene Work Zone Alerts for Drivers and Workers | 1 | 1 | 3 | 1 | 1 | 5 | General Road User | Yes | Yes | 2 |
| Reduced Speed Zone Warning | 1 | 1 | 3 | 1 | 1 | 5 | General Road User | Yes | Yes | 2 |
| Incident Scene Work Zone Alerts for Drivers and Workers | 1 | 1 | 3 | 1 | 1 | 5 | Road Operators |  | Yes | 2 |
| Dynamic Transit Operations (T-DISP) | 1 | 1 | 3 | 1 | 1 | 5 | Transit | Yes | Yes | 2 |
| Automated Toll/User Fee Collection and Administration | 1 | 1 | 3 | 1 | 1 | 5 | Road Operators | Yes |  | 2 |
| High-occupancy Toll Lanes (DSRC) | 1 | 1 | 3 | 1 | 1 | 5 | Road Operators | Yes |  | 2 |
| Eco-Traffic Signal Timing | 2 | 1 | 2 | 0 | 1 | 6 | General Road User | Yes |  | 2 |
| Ad Hoc Messages | 1 | 2 | 1 | 1 | 1 | 6 | General Road User | Yes | Yes | 2 |
| CV-enabled Turning Movement & Intersection Analysis (DSRC) | 1 | 3 | 2 | 0 | 0 | 6 | Road Operators | Yes | Yes | 2 |
| Border Crossing Performance Monitoring | 1 | 2 | 2 | 0 | 1 | 6 | Road Operators | Yes |  | 2 |
| Security and Credentials Management | 1 | 2 | 3 | 0 | 1 | 8 | Automakers | Yes |  | 2 |
| Dynamic Eco-Routing | 1 | 2 | 2 | 1 | 1 | 8 | General Road User |  | Yes | 2 |
| Eco-Speed Harmonization | 1 | 2 | 2 | 1 | 1 | 8 | General Road User |  | Yes | 2 |
| Speed Harmonization SPD-HARM (DSRC) | 1 | 2 | 2 | 1 | 1 | 8 | General Road User |  | Yes | 2 |
| Speed Zone Warning (DSRC) | 1 | 2 | 2 | 1 | 1 | 8 | General Road User |  | Yes | 2 |
| Enhanced Maintenance Decision Support System | 1 | 2 | 2 | 1 | 1 | 8 | Road Operators |  | Yes | 2 |
| Eco-Approach and Departure at Signalized Intersections | 1 | 2 | 2 | 1 | 1 | 8 | General Road User | Yes |  | 2 |
| Eco-Multimodal Real-Time Traveler Information | 1 | 2 | 2 | 1 | 1 | 8 | General Road User |  |  | 2 |
| Freight Real-Time Traveler Information with Performance Monitoring (F-ATIS) (DSRC) | 1 | 2 | 2 | 1 | 1 | 8 | Road Operators |  | Yes | 2 |

| V2X APPLICATION | IMMEDIACY OF BENEFITS | PERCIEVED VALUE TO END USER | DEPLOY-MENT COMPLEXITY - STAKEHOLDER/ ECO-SYSTEM SIZE | DEPLOY-MENT COMPLEXITY - STANDARDS | DEPLOY-MENT COMPLEXITY - GENERAL TECHNICAL | COMPOSITE SCORE | END USER | POINT OF PRESCENCE (Proximity Aware) | WIRELESS AGNOSTIC | TIMEFRAME ASSESS-MENT |
|---|---|---|---|---|---|---|---|---|---|---|
| Restricted Lane Warnings | 1 | 2 | 2 | 1 | 1 | 8 | General Road User | Yes | | 2 |
| Security and Credentials Management | 1 | 2 | 3 | 0 | 1 | 8 | General Road User | | | 2 |
| Information for Maintenance and Fleet Management Systems (DSRC) | 2 | 1 | 2 | 1 | 1 | 8 | Road Operators | | Yes | 2 |
| Probe-based Pavement Maintenance (DSRC) | 1 | 2 | 2 | 1 | 1 | 8 | Road Operators | | Yes | 2 |
| Transit Vehicle at Station/Stop Warnings | 1 | 2 | 2 | 1 | 1 | 8 | General Road User | Yes | | 2 |
| Speed Harmonization SPD-HARM (DSRC) | 1 | 2 | 2 | 1 | 1 | 8 | Road Operators | | Yes | 2 |
| Variable Speed Limits for Weather-Responsive Traffic Management | 1 | 2 | 2 | 1 | 1 | 8 | Road Operators | | Yes | 2 |
| Security and Credentials Management | 1 | 2 | 3 | 0 | 1 | 8 | Road Operators | Yes | | 2 |
| Tailgating Advisory | 3 | 3 | 1 | 0 | 0 | 9 | General Road User | Yes | | 2 |
| Warnings about Hazards in a Work Zone | 3 | 1 | 2 | 0 | 1 | 9 | Road Operators | Yes | | 2 |
| [Weather] Information for Freight Carriers (DSRC) | 1 | 2 | 3 | 1 | 1 | 10 | Commercial Vehicle | | Yes | 3 |
| Container Security | 1 | 2 | 3 | 1 | 1 | 10 | Commercial Vehicle | Yes | Yes | 3 |
| Road Weather Information for Freight Carriers | 2 | 1 | 3 | 1 | 1 | 10 | Commercial Vehicle | | Yes | 3 |
| Shipment (Trailer) Tamper Monitoring [Cargo Security] | 1 | 2 | 3 | 1 | 1 | 10 | Commercial Vehicle | | Yes | 3 |
| Information and Routing Support for Emergency Responders (DSRC) | 2 | 1 | 3 | 1 | 1 | 10 | Emergency Responders | | Yes | 3 |
| Road Weather Information and Routing Support for Emergency Responders | 2 | 1 | 3 | 1 | 1 | 10 | Emergency Responders | | Yes | 3 |
| Dynamic Ridesharing (D-RIDE) | 1 | 2 | 3 | 1 | 1 | 10 | General Road User | | Yes | 3 |
| Emergency Communications and Evacuation (EVAC) (DSRC) | 2 | 1 | 3 | 1 | 1 | 10 | General Road User | | Yes | 3 |
| Road Weather Advisories and Warnings for Motorists | 2 | 1 | 3 | 1 | 1 | 10 | General Road User | | Yes | 3 |

| V2X APPLICATION | IMMEDIACY OF BENEFITS | PERCIEVED VALUE TO END USER | DEPLOY-MENT COMPLEXITY - STAKEHOLDER/ ECO-SYSTEM SIZE | DEPLOY-MENT COMPLEXITY - STANDARDS | DEPLOY-MENT COMPLEXITY - GENERAL TECHNICAL | COMPOSITE SCORE | END USER | POINT OF PRESCENCE (Proximity Aware) | WIRELESS AGNOSTIC | TIMEFRAME ASSESS-MENT |
|---|---|---|---|---|---|---|---|---|---|---|
| Smart Park and Ride System | 2 | 1 | 3 | 1 | 1 | 10 | General Road User | | Yes | 3 |
| WX-INFO (DSRC) | 2 | 1 | 3 | 1 | 1 | 10 | General Road User | | Yes | 3 |
| HAZMAT Monitoring and Response | 2 | 1 | 3 | 1 | 1 | 10 | Road Operators | | Yes | 3 |
| Transit Pedestrian Indication | 2 | 1 | 3 | 1 | 1 | 10 | Pedestrians | Yes | | 3 |
| Transit Pedestrian Indication | 2 | 1 | 3 | 1 | 1 | 10 | Transit | Yes | | 3 |
| CV-enabled Origin-Destination Studies (DSRC) | 1 | 3 | 2 | 1 | 1 | 12 | Road Operators | | Yes | 3 |
| Infrastructure Management | 2 | 2 | 1 | 1 | 1 | 12 | Road Operators | | | 3 |
| Wait Time and Other Traveler Information | 2 | 2 | 2 | 1 | 1 | 16 | General Road User | | Yes | 3 |
| Ad Hoc Messages | 2 | 2 | 2 | 1 | 1 | 16 | Road Operators | | Yes | 3 |
| Cooperative Adaptive Cruise Control | 2 | 2 | 2 | 1 | 1 | 16 | General Road User | | | 3 |
| Eco-Cooperative Adaptive Cruise Control | 2 | 2 | 2 | 1 | 1 | 16 | General Road User | | | 3 |
| Spot Weather Impact Warning | 2 | 2 | 3 | 1 | 1 | 20 | General Road User | | Yes | 3 |
| Excess Emission Identification from Trucks and Cars [Emissions Analysis] | 2 | 2 | 3 | 1 | 1 | 20 | Road Operators | | | 4 |
| Approach Lane Use Management | 2 | 3 | 2 | 1 | 1 | 24 | Road Operators | | Yes | 4 |
| Connected Eco-Driving | 3 | 2 | 2 | 1 | 1 | 24 | General Road User | | | 4 |
| Eco-Lanes Management | 3 | 2 | 2 | 1 | 1 | 24 | Road Operators | | | 4 |
| Eco-Ramp Metering | 3 | 2 | 2 | 1 | 1 | 24 | Road Operators | | | 4 |
| Congestion Pricing | 2 | 3 | 3 | 1 | 1 | 30 | Road Operators | | | 4 |
| Data Distribution | 2 | 3 | 3 | 1 | 1 | 30 | Road Operators | | | 4 |
| Low Emissions Zone Management | 3 | 2 | 3 | 1 | 1 | 30 | Road Operators | | | 4 |
| Intermittent Bus Lanes | 3 | 2 | 3 | 1 | 1 | 30 | Transit | | | 4 |
| Advanced Automatic Crash Notification Relay | 3 | 3 | 3 | 1 | 1 | 45 | General Road User | | Yes | 4 |

# Appendix B: DSRC Market Adoption Model Equations

(01) advertisement effectiveness=
1e-005
Units: 1/Month
Effectiveness of marketing effects: percentage of non-equipped vehicles that install DSRC due to marketing effects (effect is per month)

(02) Aftermarket Equipped Vehicles=
heavy vehicles installing DSRC+light vehicles installing DSRC
Units: Vehicles/Month
Number of vehicles (both light and heavy) installing DSRC in the aftermarket per month. It is not a cumulative variable. The value represents thousands of vehicles per month.

(03) approval ratio=
0.6
Units: Dmnl
Approaval rate of initially developed apps.

(04) Apps being tested= INTEG (
apps to be tested-apps gaining approval-apps require debug,
0)
Units: Applications

(05) apps gaining approval=
Apps being tested*approval ratio/test time
Units: Applications/Month

(06) apps require debug=
Apps being tested*(1-approval ratio)/test time
Units: Applications/Month

(07) apps to be tested=
Apps Under Development/developing time
Units: Applications/Month

(08) Apps Under Development= INTEG (
apps require debug+initiaing new apps development-apps to be tested,
0)
Units: Applications

(09) average urban VMT heavy vehicles=
12756
Units: Miles/Vehicles
Average VMT of heavy vehicles in the urban areas
=26016*131011/267207

(10) average urban VMT light vehicles=
7789
Units: Miles/Vehicles
Average VMT of light vehicles in the urban areas
=11318*1821576/2646641

(11) Baseline Switch=
0
Units: 1
This is a swtich to ask the model to consider the aftermarket
effects or not. For aftermarket effects to be present in the
model set the value to 0. In order to eliminate the aftermarket
effects, set value to 1.

(12) Calendar Year=
Years+2015
Units: **undefined**

(13) contact rate=
5
Units: Contact/Vehicles/Month
WOM model parameter. This is a measure for the number of
contacts any DSRC equipped vehicle owner will make per months.

(14) "contacts between DSRC users and non-users"=
contact rate*(Light Vehicles with DSRC+Heavy Vehicles with DSRC)*potential
vehicles concentration
Units: Contact/Month
number of contacts with the non-equipped vehicle owners by
equipped vehicle owners per month.

(15) developing time=
12
Units: Months
average developing (and re-developing) time of the apps.

(16) DSRC installed sites= INTEG (
improving infrastructure,
0)
Units: Sites

(17) DSRC utility=
potential apps utility*(w0 + w1*v2v network potential + w2*infrastructure
concentration
)
Units: Dmnl
All DSRC utility is being delivered through apps. The potential
apps utility can only delivered if enough v2v network and
infrastructure is available.

(18) equipped VMT=

Light Vehicles with DSRC*average urban VMT light vehicles+Heavy Vehicles with DSRC
*average urban VMT heavy vehicles
Units: Miles
Equipped urban VMT of vehicles in thousands of miles

(19) FINAL TIME = 600
Units: Month
The final time for the simulation.

(20) heavy vehicle monthly sales=
729/12
Units: Month
729,000 annual sale of heavy vehicle is assumed

(21) Heavy Vehicles=
Heavy Vehicles with DSRC+Heavy Vehicles without DSRC
Units: **undefined**

(22) heavy vehicles being manufactured with DSRC=
heavy vehicle monthly sales*mandated DSRC ratio on heavy vehicles
Units: Vehicles/Month
Thousands of heavy vehicles being manufactured each month with
DSRC installed by OEM.

(23) heavy vehicles being manufactured without DSRC=
heavy vehicle monthly sales*(1-mandated DSRC ratio on heavy vehicles)
Units: Vehicles/Month
Thousands of heavy vehicles being manufactured each month
without DSRC.

(24) heavy vehicles installing DSRC=
(1-Baseline Switch)*(MAX(0, heavy vehicles WOM conversions)*(1-percentage of light vehicles without DSRC of total vehicles without DSRC
)+Heavy Vehicles without DSRC*advertisement effectiveness)
Units: Vehicles/Months

(25) heavy vehicles life cycle=
15.09*12
Units: **undefined**
Lifecycle of heavy vehicle is assumed to be 11/0.729=15.09 years

(26) Heavy Vehicles with DSRC= INTEG (
heavy vehicles being manufactured with DSRC+heavy vehicles installing DSRC
-heavy vehicles with DSRC depletion,
0)
Units: Vehicles
Total number of heavy vehicles with DSRC installed. The value is
in thousands of vehicles. Initial value (initial number of heavy
vehicles with DSRC) is set to 0.

(27) heavy vehicles with DSRC depletion=
Heavy Vehicles with DSRC/heavy vehicles life cycle
Units: Vehicles/Month
Heavy vehicles with DSRC being desposed. Thousands of vehicles per month.

(28) Heavy Vehicles without DSRC= INTEG (
heavy vehicles being manufactured without DSRC-heavy vehicles installing DSRC -heavy vehicles without DSRC depletion,
11000)
Units: Vehicles
Total number of light vehicles without DSRC installed. The value is in thousands of vehicles. Initial value (initial number of light vehicles with DSRC) is set to 11 million.

(29) heavy vehicles without DSRC depletion=
Heavy Vehicles without DSRC/heavy vehicles life cycle
Units: Vehicles/Month
Heavy vehicles without DSRC being desposed. Thousands of vehicles per month.

(30) heavy vehicles WOM conversions=
Perceived Utilites*"contacts between DSRC users and non-users"*ideal heavy vehicle adoption fraction
Units: **undefined**
Number of vehicles (in thousands) installing DSRC ( in aftermarket) per month due to WOM.

(31) ideal adoption fraction=
0.03
Units: Vehicles/Contact
WOM model parameter. percentage of contacts which will yield to equipped vehicles. This is the ideal value. If the perceived benefit or value of the DSRC be at its maximum 1 then this is the adoption fraction of the conacts. This will be corrected by the Perceived Utility variable.

(32) ideal heavy vehicle adoption fraction=
0.03
Units: **undefined**

(33) improving infrastructure=
IF THEN ELSE(threshold*total VMT < equipped VMT, IF THEN ELSE(DSRC installed sites
<= 300, infrastructure improvement rate
, 0), 0)
Units: Sites/Month

(34) infrastructure concentration=
DSRC installed sites/total infrastructure sites
Units: 1

(35) infrastructure improvement rate=
300/108
Units: Sites/Month
infrastructure improvement rate. 300,000 sites in 9 years. The
rate is constant at this level, the model however takes into
account all the 300,000 sites.

(36) initiaing new apps development=
STEP(1, 0)*"Table1: Effect of number of potential apps on apps decelopment"
(Potential Apps)/12
Units: Applications/Month

(37) initial number of apps=
5
Units: Applications

(38) INITIAL TIME = 0
Units: Month
The initial time for the simulation.

(39) known light vehicle production manufactured with DSRC=
10
Units: **undefined**
Cadillac CTS will have DSRC equipped, forecast monthly
production about 10

(40) light vehicle monthly sales=
15000/12
Units: **undefined**
15M is annual light vehicle production in thousands

(41) Light Vehicles=
Light Vehicles with DSRC+Light Vehicles without DSRC
Units: **undefined**

(42) light vehicles being manufactured with DSRC=
mandated DSRC ratio on light vehicles*(light vehicle monthly sales-known light
vehicle production manufactured with DSRC
)+known light vehicle production manufactured with DSRC
Units: Vehicles/Month
Thousands of light vehicles being manufactured each month with
DSRC installed by OEM.

(43) light vehicles being manufactured without DSRC=
(1-mandated DSRC ratio on light vehicles)*light vehicle monthly sales
Units: Vehicles/Month
Thousands of light vehicles being manufactured each month
without DSRC.

(44) light vehicles installing DSRC=

(1-Baseline Switch)*(MAX(0, WOM conversions)*percentage of light vehicles without DSRC of total vehicles without DSRC
+Light Vehicles without DSRC
*advertisement effectiveness)
Units: Vehicles/Month

(45) light vehicles life cycle=
15.6*12
Units: Month
Life cycle of light vehicles: 234/15=15.6 years multiplied by 12 months

(46) Light Vehicles with DSRC= INTEG (
light vehicles being manufactured with DSRC+light vehicles installing DSRC
-light vehicles with DSRC depletion,
0)
Units: Vehicles
Total number of light vehicles with DSRC installed. The value is in thousands of vehicles. Initial value (initial number of light vehicles with DSRC) is set to 0.

(47) light vehicles with DSRC depletion=
Light Vehicles with DSRC/light vehicles life cycle
Units: Vehicles/Month
Light vehicles with DSRC being desposed. Thousands of vehicles per month.

(48) Light Vehicles without DSRC= INTEG (
light vehicles being manufactured without DSRC-light vehicles installing DSRC
-light vehicles without DSRC depletion,
234000)
Units: Vehicles
Total number of light vehicles without DSRC installed. The value is in thousands of vehicles. Initial value (initial number of light vehicles with DSRC) is set to current number of light vehicles that is 234 million.

(49) light vehicles without DSRC depletion=
Light Vehicles without DSRC/light vehicles life cycle
Units: Vehicles/Month
Light vehicles without DSRC being desposed. Thousands of vehicles per month.

(50) mandated DSRC ratio on heavy vehicles=
STEP(1, 84)
Units: Dmnl

(51) mandated DSRC ratio on light vehicles=
STEP(0.3, 48) + STEP(0.3, 60) + STEP(0.3, 72) + STEP(0.1, 84)
Units: Dmnl
this is the mandated DSRC equipped production ratio mandate.

(52) Number of Apps= INTEG (
apps gaining approval,
initial number of apps)
Units: Applications
Number of developed apps

(53) OEM Equipped Vehicles=
heavy vehicles being manufactured with DSRC+light vehicles being manufactured with DSRC
Units: Vehicles/Month
Number of vehicles (both light and heavy) being manufactued with DSRC installed by the OEM per month. It is not a cumulative variable. It represents thousands of vehicles per month manufactured with DSRC by OEM.

(54) Perceived Utilites=
SMOOTH3(DSRC utility, time delay 1)
Units: Dmnl

(55) percentage of heavy vehicles with DSRC=
Heavy Vehicles with DSRC/Heavy Vehicles*100
Units: **undefined**

(56) percentage of light vehicles with DSRC=
Light Vehicles with DSRC/Light Vehicles*100
Units: **undefined**

(57) percentage of light vehicles without DSRC of total vehicles without DSRC
=
Light Vehicles without DSRC/(Light Vehicles without DSRC+Heavy Vehicles without DSRC
)
Units: 1
percentage of light vehicles not already equipped in the population of all vehicles that are not yet equipped. this variables is used to determine how much of the word of mouth effect will be related to light vehicles and how much will be related to heavy vehicles.

(58) percentage of vehicles with DSRC=
(Light Vehicles with DSRC+Heavy Vehicles with DSRC)/(Light Vehicles with DSRC
+Light Vehicles without DSRC+Heavy Vehicles with DSRC+Heavy Vehicles without DSRC
)*100
Units: 1
percentage of DSRC equipped vehicles (in both light and heavy vehicles)

(59) Potential Apps= INTEG (
-initiaing new apps development,
121)

Units: Applications

(60) potential apps utility=
1 - EXP(-Number of Apps*utility constant)
Units: 1
Exponential utility function.

(61) potential vehicles concentration=
(Light Vehicles without DSRC+Heavy Vehicles without DSRC)/total market
Units: 1
concentration of non-equipped vehicle owners in the total
population of vehicle owners.

(62) SAVEPER =
TIME STEP
Units: Month [0,?]
The frequency with which output is stored.

(63) "Table1: Effect of number of potential apps on apps decelopment"(
[(0,0)-(122,30)],(0,0),(2.2,2.2),(4.4,2.2),(6.6,2.2),(8.8,2.2),(11,2.2),(
15.8,4.8),(20.6,4.8),(25.4,4.8),(30.2,4.8),(35,4.8),(62,27),(89,27),(122,27
))
Units: Applications/Months
This table relates the number of remaining potential apps to the
rate developers develop new apps.

(64) test time=
6
Units: Months
testing time of the apps.

(65) threshold=
0.4
Units: 1
Threshold for improving infrastructure sites.

(66) time delay 1=
6
Units: Months
Time delay for the market to update their perception of DSRC
utility.

(67) TIME STEP = 0.125
Units: Month [0,?]
The time step for the simulation.

(68) total infrastructure sites=
300
Units: Sites

(69) total market=

Light Vehicles without DSRC+Light Vehicles with DSRC+Heavy Vehicles with DSRC
+Heavy Vehicles without DSRC
Units: Vehicles
total number of vehicles at any given time.

(70) total VMT=
(Light Vehicles with DSRC+Light Vehicles without DSRC)*average urban VMT light vehicles
+(Heavy Vehicles with DSRC
+Heavy Vehicles without DSRC)*average urban VMT heavy vehicles
Units: Miles
Total urban VMT of vehicles in thousands of miles

(71) utility constant=
0.05
Units: 1/Applications
This is the constant in the exponential utility function. This value is calculated by fitting an exponential function on the average perceived value.

(72) v2v network potential=
(equipped VMT/total VMT)^2
Units: 1
V2V potential network utility.

(73) w0=
0
Units: **undefined**
Base utility (= day 1 utility) w0 + w1 + w2 must equal zero

(74) w1=
0.5
Units: 1
Relative weight for V2V apps. (w0 + w1 + w2 must equal 1)

(75) w2=
0.5
Units: 1
Relative weight for V2I apps. (w0 + w1 + w2 must equal 1)

(76) WOM conversions=
Perceived Utilites*"contacts between DSRC users and non-users"*ideal adoption fraction
Units: Vehicles/Month
Number of vehicles (in thousands) installing DSRC ( in aftermarket) per month due to WOM.

(77) Years=
Time/12
Units: **undefined**

# Appendix C: Select Bibliography

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