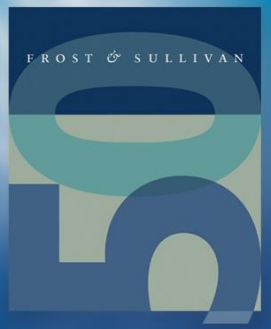
Vehicle-to-Everything Technologies for Connected Cars

DSRC and Cellular Technologies Drive Opportunities

TechVision Group of Frost & Sullivan



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FROST & SULLIVAN

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1.0 Executive Summary

1.1 Research Scope

Advancements in wireless communication technologies, sensor fusion, imaging technologies, Big Data, and analytics have created opportunities for automotive manufacturers to discover a wide range of solutions for multiple applications. Miniaturization of electronic components, advancements in navigation, and adoption of smart devices is expected to fuel advancements in the vehicle-to-everything (V2X) communications industry.

Vehicle-to-everything (V2X) communication is expected to be pivotal in the development of Internet of Things (IoT). Apart from devices talking to each other, future connected cars will interact with the environment around, thereby leading to various forms of vehicular communication. Though government initiatives, evolving ADAS (advanced driver assistance systems) applications and technology advancements may drive opportunities, high initial investment and lack of suitable infrastructure are some of the key factors that hinder widespread adoption.

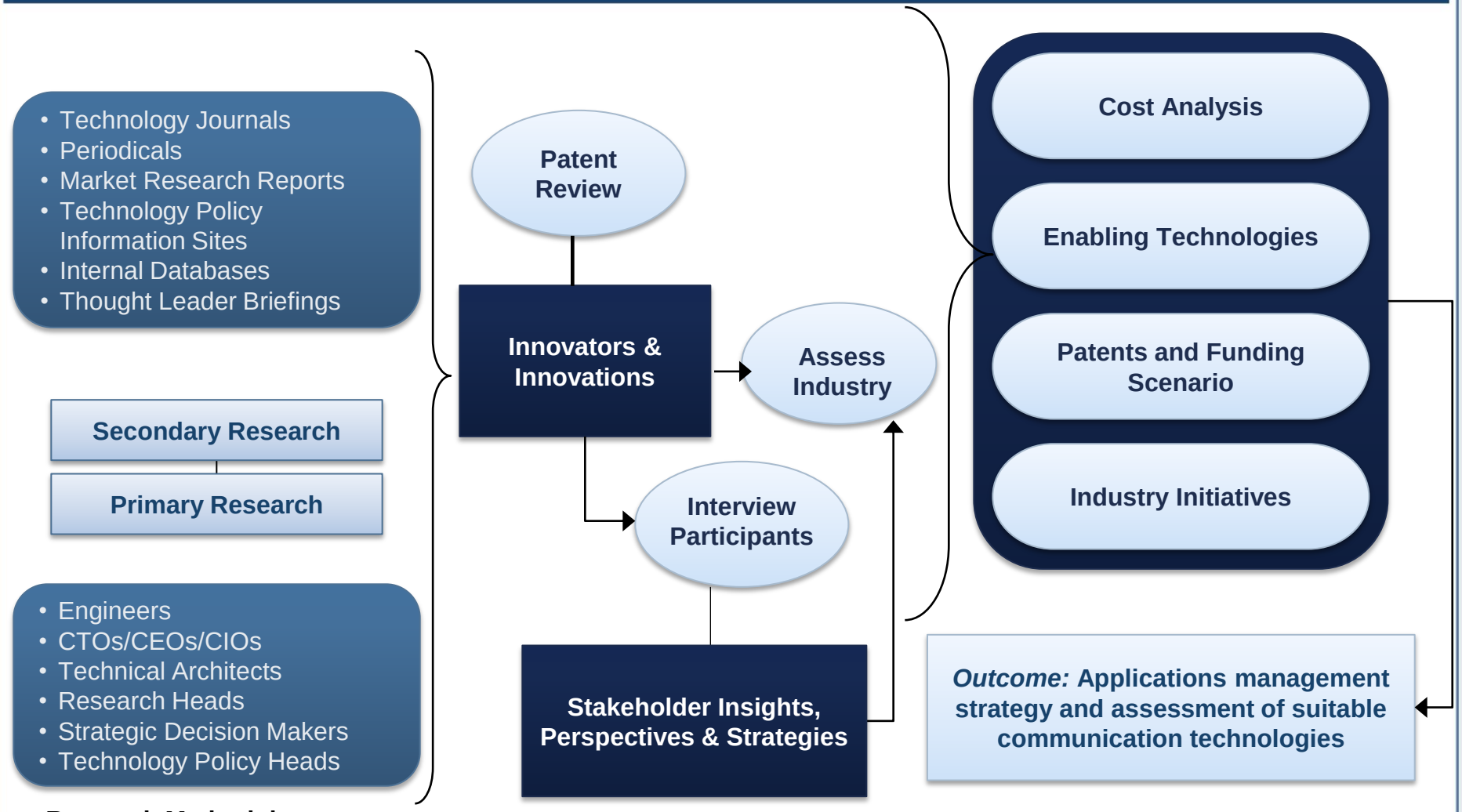
This technology and innovation report focuses on capturing applications of vehicle-to-vehicle (V2V) and V2X. Cost analysis was done to assess suitable communication technologies for V2X communication.

Key questions addressed in the research service:

- What are the various applications of V2V and vehicle-to-infrastructure (V2I)?
- What are the different types of communication technologies that can be adopted in V2X?
- What are the factors influencing adoption of V2X communication?
- What is the suitable communication technology for V2X communication?
- What is the application pipeline for V2X communication?
- What are future growth opportunities?

Source: Frost & Sullivan

1.2 Research Methodology



Source: Frost & Sullivan

1.3 Research Methodology Explained

Step 1: To provide a thorough analysis of each topic, *TechVision* analysts perform a review of patents to become familiar with the major developers and commercial participants and their processes.

Step 2: Building on the patent search, the analysts review abstracts to identify key scientific and technical papers that provide insights into key industry participants and the technical processes, on which they work.

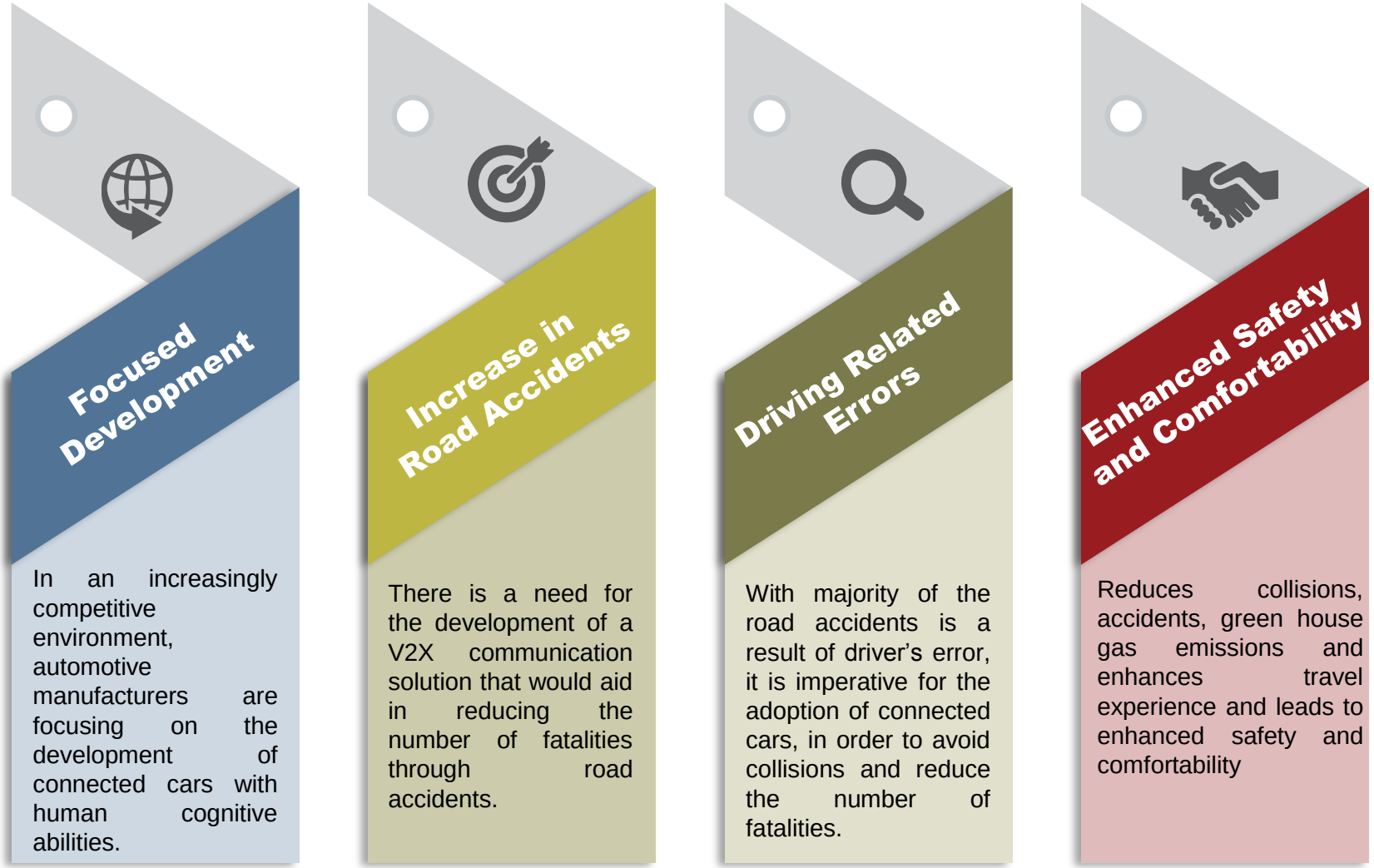
Step 3: The analysts then create a detailed questionnaire with content created to address the research objectives of the study, which functions as a guide during the interview process. While the analysts use structured questionnaires to guarantee coverage of all the desired issues, they also conduct interviews in a conversational style. This approach results in a more thorough exchange of views with the respondents, and offers greater insight into the relevant issues than more structured interviews may provide.

Step 4: The analysts conduct primary research with key industry participants and technology developers to obtain the required content. Interviews are completed with sources located throughout the world, in universities, national laboratories, governmental and regulatory bodies, trade associations, and end-user companies, among other key organizations. Our analysts contact the major commercial participants to find out about the advantages and disadvantages of processes and the drivers and challenges behind technologies and applications. Our analysts talk to the principal developers, researchers, engineers, business developers, analysts, strategic planners, and marketing experts, among other professionals.

Step 5: The project management and research team reviews and analyzes the research data that are gathered and adds its recommendations to the draft of the final study. Having conducted both published studies and custom proprietary research covering many types of new and emerging technology activities as well as worldwide industry analysis, the management and research team adds its perspective and experience to provide an accurate, timely analysis. The analysts then prepare written final research services for each project and sometimes present key findings in analyst briefings to clients.

Source: Frost & Sullivan

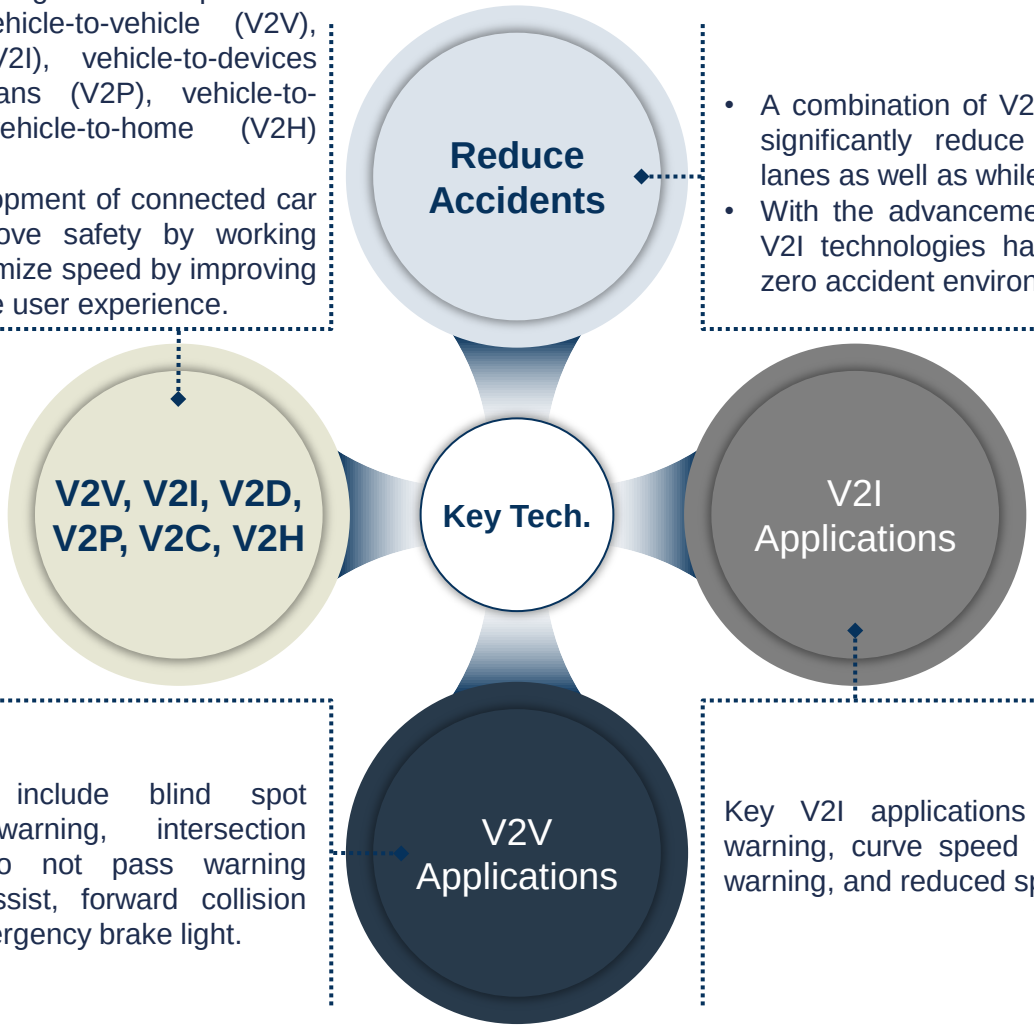
1.4 Key Findings – Significance of Connected Cars



Source: Frost & Sullivan

1.5 Key Findings – Key Connected Car Technologies - V2V and V2I Applications can Significantly Reduce Collisions

- The key technologies enabling the development of connected cars are vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), vehicle-to-devices (V2D), vehicle-to-pedestrians (V2P), vehicle-to-cloud (V2C), and vehicle-to-home (V2H) technologies.
- The key reasons for development of connected car technologies are to improve safety by working toward zero accidents, optimize speed by improving fuel efficiency, and enhance user experience.



- A combination of V2V and V2I applications can significantly reduce collisions while changing lanes as well as while intersecting.
- With the advancement in technology, V2V and V2I technologies have the calibre to create a zero accident environment in near future.

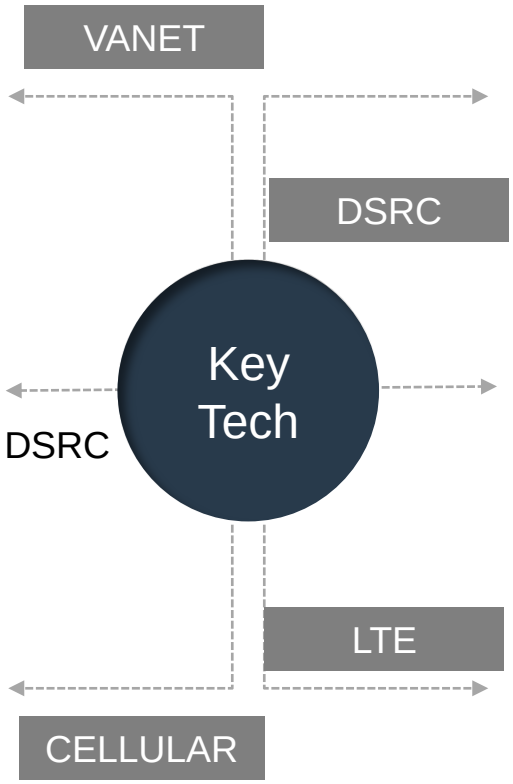
Key V2V applications include blind spot warning/lane change warning, intersection movement assistance, do not pass warning (DNPW), left/right turn assist, forward collision warning, and electronic emergency brake light.

Key V2I applications include oversize vehicle warning, curve speed warning, red light violation warning, and reduced speed zone warning.

Source: Frost & Sullivan

1.6 Key Findings – DSRC and Cellular Technologies are Key Communication Technologies for V2X

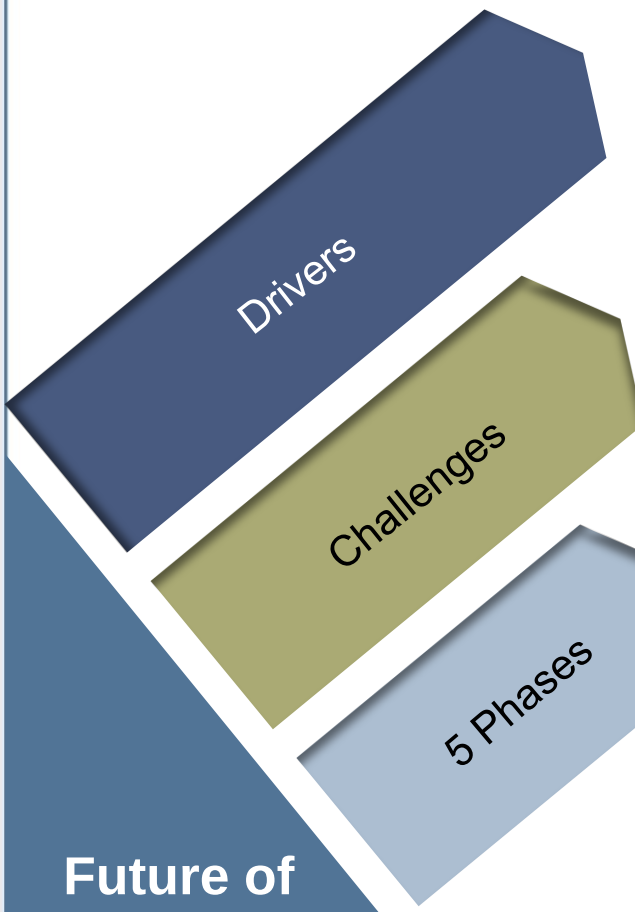
- Vehicular ad hoc networks (VANETs) are technologies developed specifically for the purpose of vehicular communication. It is a class of mobile ad-hoc networks (MANETs), which play an important role in the development of intelligent transport systems (ITS).
- Some of the key wireless communication technologies that have an impact in VANET include cellular systems, WiMAX, Microwave, Wi-Fi, DSRC (dedicated short-range communications), ZigBee, Bluetooth, and milli-meter wave communication. Cellular and DSRC prove to be potential communication technologies enabling connected cars.
- DSRC is an ad hoc technology for V2V and V2I applications, standardized on the basis of IEEE802.11p. Cellular technology for connected cars is still in a process of standardization and expected to be regulated with the launch of Release-14 of 3rd Generation Partnership Project (3GPP).



- Based on Frost & Sullivan analysis, it is evident that the cost associated with the adoption of DSRC for vehicular communication would be lesser, when compared to cellular communication technologies.
- Based on cost analysis and technology readiness level, DSRC is expected to be suitable primary communication technology for V2X communication and tentative to be adopted by the National Highway Traffic Safety Administration (NHTSA), US, for vehicular communication.
- Although C-V2X using advanced long –term evolution (LTE) is also a proposed communication technology, it is still to be commercialized with the roll out of 3GPP's Release 14. Technology readiness level and high costs incurred for deploying cellular V2X suggests that, adopting cellular technologies for V2X communication could delay the implementation of V2V and V2I applications.

Source: Frost & Sullivan

1.7 Key Findings – Future Opportunities



01 Increased interest in the adoption of V2X by government agencies, industry consolidation, technology advancements, and increased demand for ADAS is driving development in this space.

02 Cyber security, lack of sophisticated infrastructure, overall cost associated, and ambiguity over communication technologies hinders adoption.

03 V2X applications in the next few years are expected to be positioned under five phases. Phase 1 is awareness driving application, phase 2 is sensing driving, phase 3 is cooperative driving, phase 4 is synchronized cooperative driving, and phase 5 is autonomous driving.

Future of Connected Cars

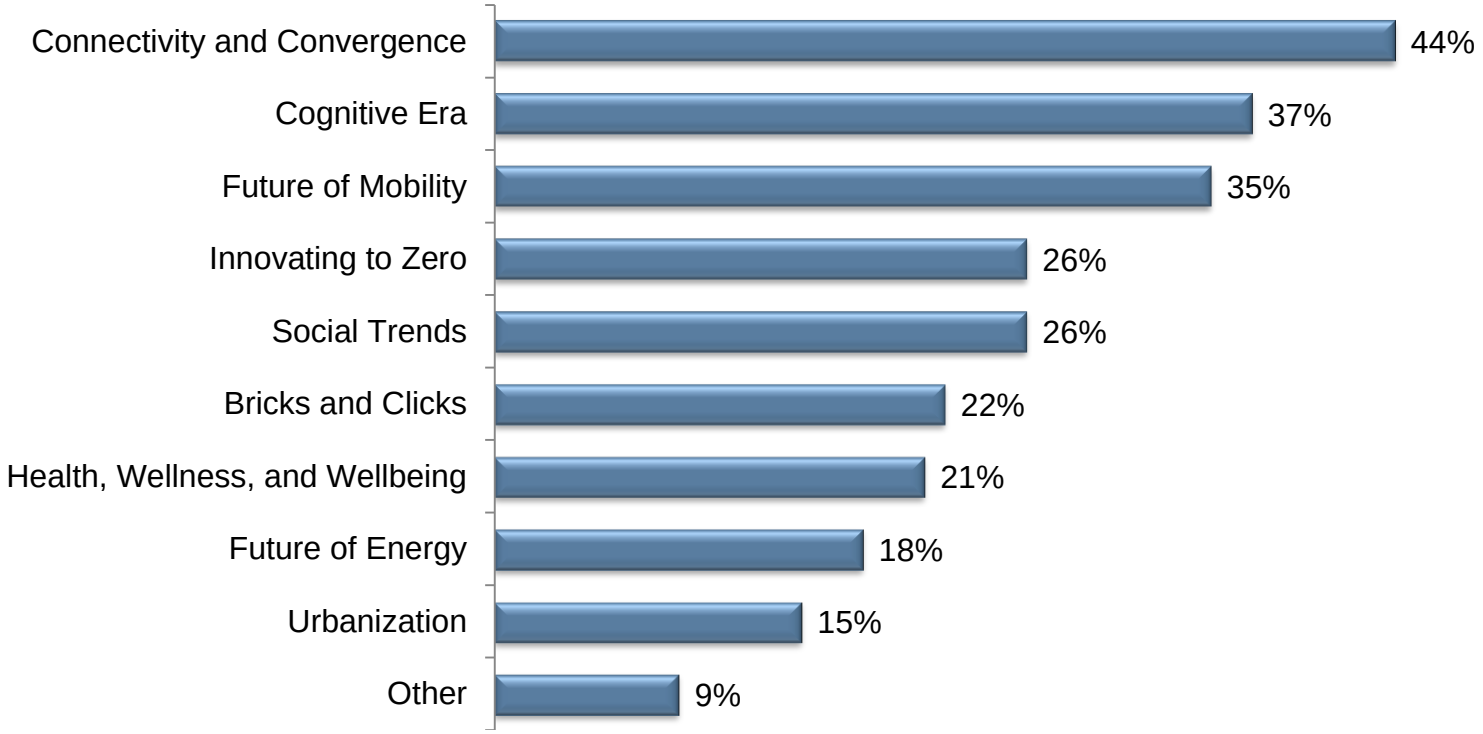
Source: Frost & Sullivan

2.0 Significance and Key Technologies

2.1 Potentially Disruptive Mega Trends – Significance of Connectivity and Future of Mobility from CEO's Perspective

Connectivity and convergence is indicated as most disruptive Mega Trend. It has direct and indirect influence on most other Mega Trends.

Disruptive Mega Trend, Global, 2016



Base: All respondents (n=303)
Q16. Which Mega Trends could potentially disrupt your organization? (MAXIMUM 3 RESPONSES)

Source: Frost &Sullivan Report on "CEOs' Perspectives on Growth, Innovation, and Leadership", K144 published September 2016

Note: All figures are rounded.

2.2 V2X in Connected Cars will Reduce Automotive Collision

What do we mean by Connected Cars?

- Connected Cars are vehicles which have access to internet and are equipped with a variety of sensors, (LiDARs , radar) and cameras – enabling communication with other vehicles, road infrastructure and entities which are connected to each other over the same network infrastructure.
- In the future, a connected car will be compared to an intelligent computational device on wheels.
- It can interpret and analyse data from the surroundings and augment it with the supporting technologies in the vehicle to enhance the human cognitive abilities.

Why do we need Connected Cars?

- According to a World Health Organization report, nearly 1.25 million fatalities are caused every year because of road accidents. A majority of these accidents are due to error during driving. The primary aim for the adoption of connected cars is to avoid collisions and reduce fatalities.
- Several work hours are wasted globally as a result of traffic jams. Connected cars technologies are capable of optimizing the road space with their intelligent systems and reduce road congestions.
- Wastage of fuel and the resulting greenhouse gases play a significant role in global warming. The technologies in connected cars enable fuel efficient vehicles thereby reducing the waste of fuel and the emission of greenhouse gases.
- In addition to safety and reducing road congestion and with evolution of cellular technologies for connectivity, connected cars will enable various intelligent navigation systems and multimedia services in the short- to medium-term, resulting in better travel experience.

V2X Benefits

- **Reduces collisions**
- **Reduces road congestion**
- **Reduces greenhouse gas emission**
- **Enhances travel experience**

Source: Frost & Sullivan

2.3 Connected Car – Device on Wheels

What does Connected Cars offer?

Toward Zero Accidents

- Successful implementation of V2V and V2I technologies will result in significant reduction in collisions.
- Connected car technologies and applications will alert the driver about hazardous situations much earlier, enabling more reaction time for the driver to prevent an accident.

Optimizing Speed for Fuel Efficiency

- A connected car is capable of communicating with roadside infrastructure connected over a cloud, thereby providing alerts to the driver about traffic jams, bad roads, and so on.
- These alerts can help the driver to optimize vehicle speed and reduce fuel wastage.

Correct the Driving Pattern

- The intelligent technologies in connected cars can also provide information such as alternative routes to avoid traffic.
- The connected vehicle can also be integrated with the traveler's smartphone for receiving notifications/alerts about location of restaurants, petrol stations nearby.

Increased Safety

Increased Fuel Efficiency

Better User Experience

Source: Frost & Sullivan

2.4 The Three Big Impact of Connected Cars

Impact of Connected Cars on traffic and Environment

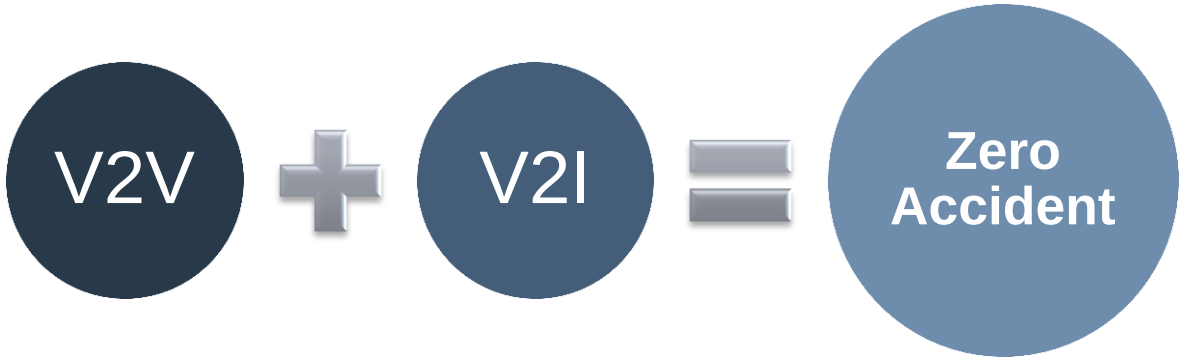
During harsh weather conditions, or when the visibility is poor, proper implementation of connected traffic management systems can reduce accidents by 25%.

Intelligent traffic system applications can reduce travel time by 23% for emergency vehicles (hospital ambulances, fire engines), and by 27% for other vehicles.

Optimized use of lane management systems and traffic management systems can reduce carbon dioxide (CO_2) emissions by 11% and can account for fuel saving up to 22%.

Source: US Department of Transportation (US DOT), Frost & Sullivan

2.5 V2V and V2I Together will Lead to Zero Accidents



- According to Frost & Sullivan analysis and industry experts, it is estimated that successful implementation of **V2V and V2I technologies** can reduce up to 80% of non-impaired crashes. A combination of V2V and V2I applications can significantly reduce collisions while changing lanes as well as during intersections. With the advancement in technology, ***V2V and V2I technologies have the caliber to create a zero accident environment*** in the near future.
- While V2V and V2I technologies are not only easy to implement, they are more cost-effective than deploying radars and imaging systems in every vehicle.
- V2V + V2I leverages traffic management systems with data related to speed and position of every vehicle, thereby efficiently controlling the flow of traffic. This data significantly reduces the time involved in urban congestion, time to find parking spots, and wastage of fuel.

Source: Frost & Sullivan

2.6 Key Technologies Enabling Connected Cars

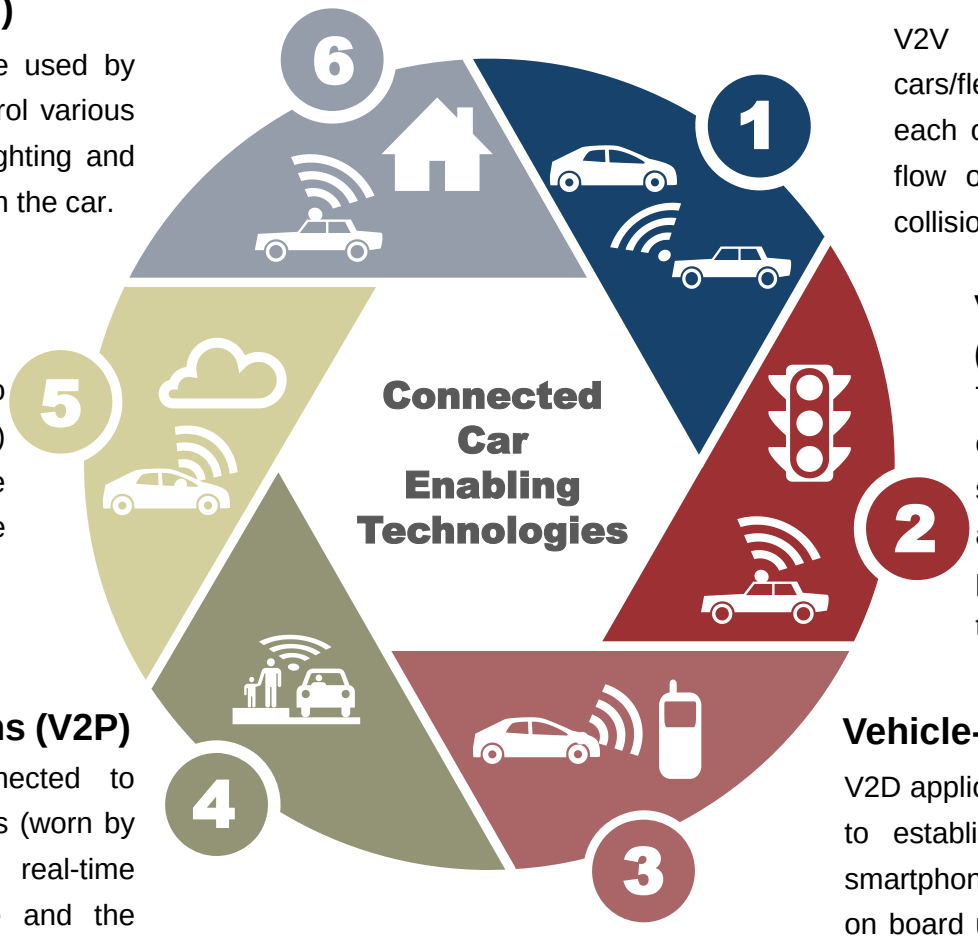
Technologies enabling connected cars

Vehicle-to-home (V2H)

A connected vehicle can be used by the owner of the car to control various home appliances such as lighting and air conditioners while sitting in the car.

Vehicle-to-vehicle (V2V)

V2V technology enables cars/fleet to communicate with each other resulting in improved flow of traffic and reduction in collisions.



Vehicle-to-cloud (V2C)

A vehicle can be connected to the cloud for over the air (OTA) software upgrades to update information including the connected module.

Vehicle-to-infrastructure (V2I)

The connected vehicle can be connected to roadside units such as traffic lights, which act as communication nodes providing various safety and traffic updates.

Vehicle-to-pedestrians (V2P)

A vehicle can be connected to smartphones and wearables (worn by pedestrians) to provide real-time information to the vehicle and the pedestrians and avoid collisions.

Vehicle-to-devices (V2D)

V2D application enables vehicle to establish connectivity with smartphone or other installed on board units (OBUs) such as infotainment systems.

Source: Frost & Sullivan

3.0 Key V2V and V2I Applications

3.1 Key Vehicle-to-Vehicle enabled Applications

Blind Spot Warning (BSW)/ Lane Change Warning (LCW)

While changing a lane, BSW/LCW feature of V2X notifies the driver about other vehicle travelling in the same direction to avoid collision.

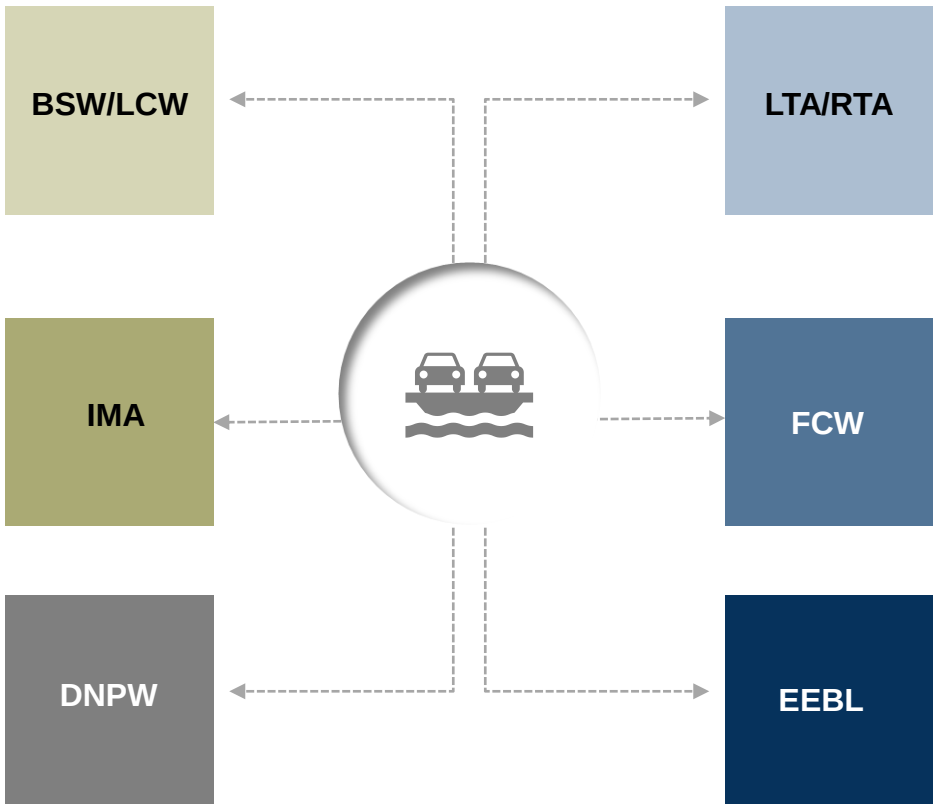
Intersection Movement Assist (IMA)

IMA sends an alert to the driver in case of a potential collision at cross points in the road.

Do Not Pass Warning (DNPW)

DNPW is similar to the BSW/LCW feature, which notifies the driver about another vehicle travelling in the vicinity, but in the opposite direction.

V2V Applications enabled through connectivity



Left Turn Assist (LTA)/ Right Turn Assist (RTA)

It is a feature similar to IMA that notifies the driver of a potential collision with another vehicle at the intersection while turning left/right.

Forward Collision Warning (FCW)

FCW assists the driver in maintaining a safe distance with the vehicle in the front to avoid rear-end collision.

Electronic Emergency Brake Light (EEBL)

On application of emergency brake, a notification is sent to the surrounding vehicles about the braking event to alert the surrounding vehicles to avoid any accidents.

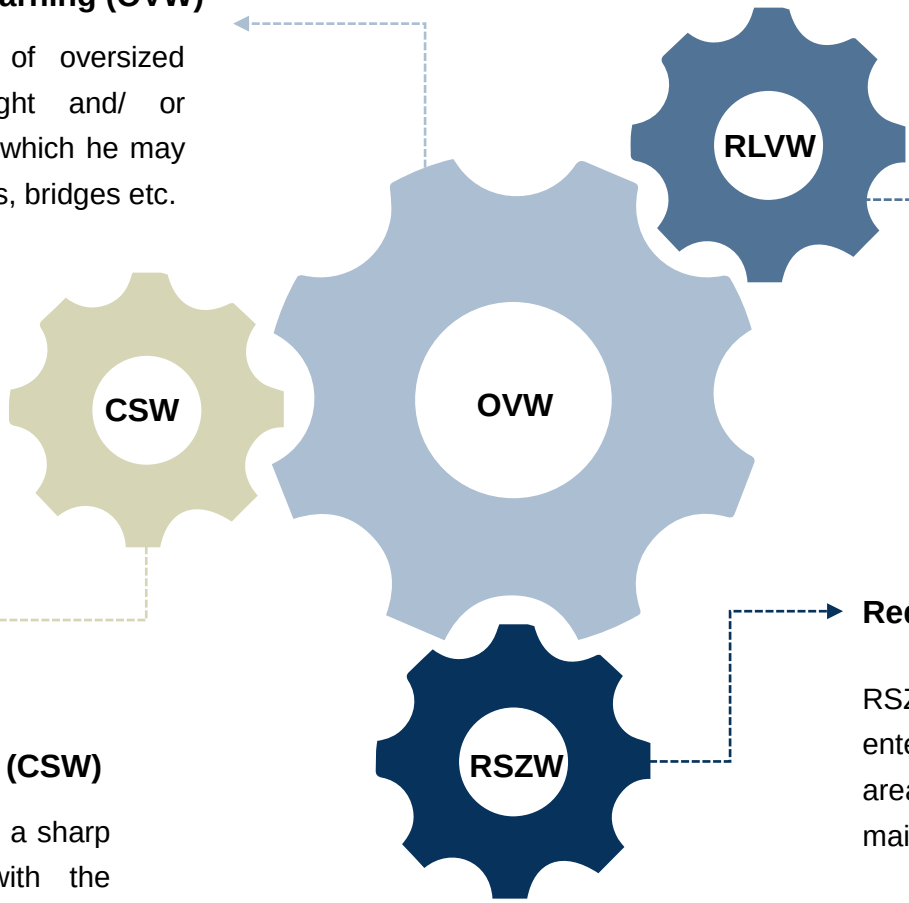
Source: Frost & Sullivan

3.2 Key Vehicle-to-Infrastructure enabled Applications

V2I Applications enabled through connectivity

Oversize Vehicle Warning (OVW)

OVW alerts drivers of oversized vehicles about height and/ or horizontal restrictions which he may come across in tunnels, bridges etc.



Red Light Violation Warning (RLVW)

RLVW feature updates the driver about the timing of traffic light and alerts him of a potential danger in case of red light violation.

Curve Speed Warning (CSW)

CSW alerts the driver of a sharp curve ahead along with the speed limit information to avoid any accidents.

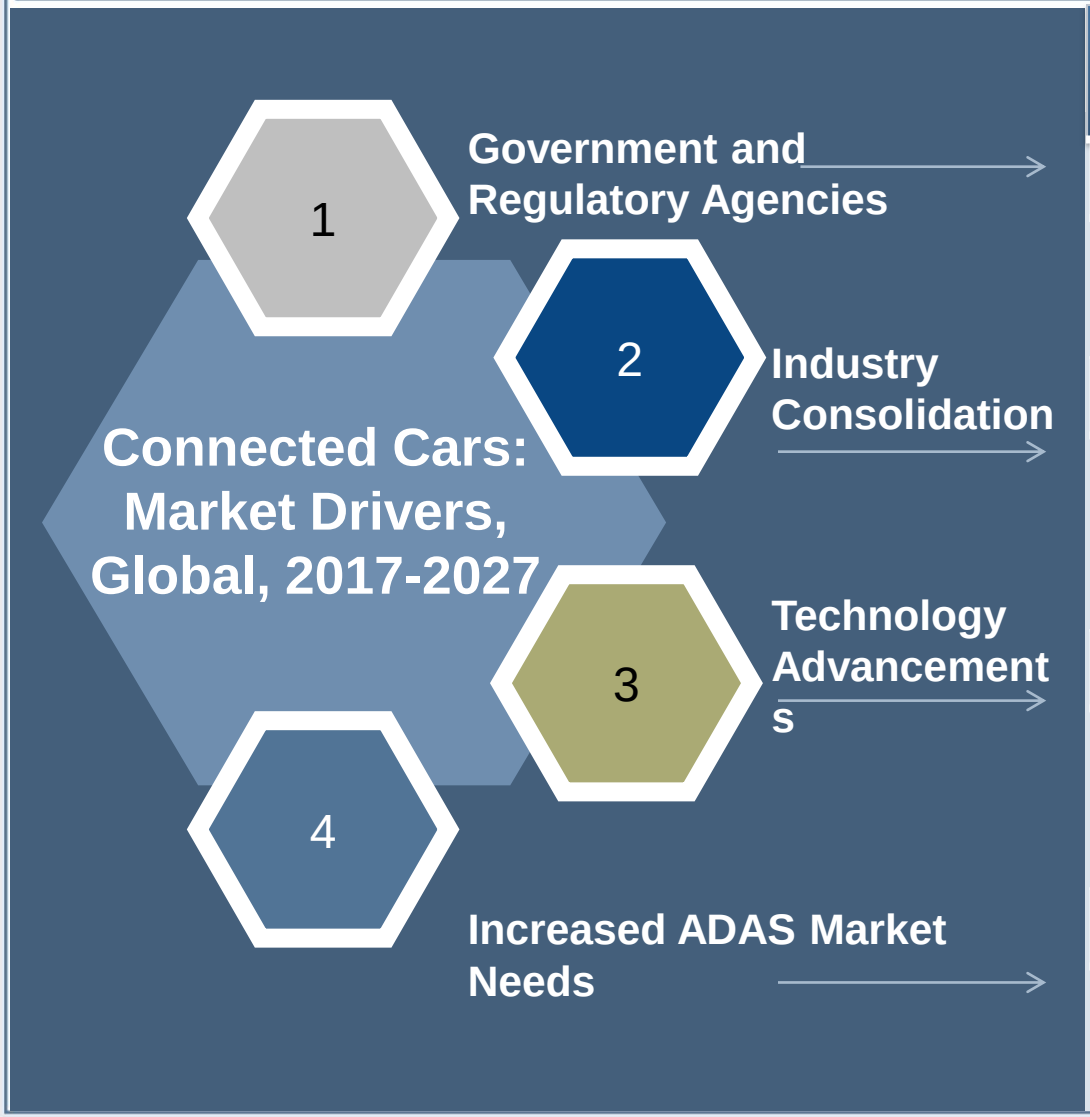
Reduced Speed Zone Warning (RSZW)

RSZW updates the driver when a vehicle enters work zone or other congested areas, alerting him about speed limit to be maintained.

Source: Frost & Sullivan

4.0 Impact Assessment of Factors Influencing Development and Adoption – Drivers and Challenges

4.1 Regulations, Industry Consolidation, Technology Advancements, and Increasing Needs Drives Development and Adoption



Short Term (1–2 Years)	Medium Term (3–4 Years)	Long Term (5-11 Years)
High	High	High
High	High	Medium
High	High	High
High	High	High

Source: Frost & Sullivan

4.2 Government and Regulatory Agencies are Driving Implementation of Connected Cars

Term	Near-term	Medium term	Long term
Level of Impact	High	High	High

- Government Agencies & Regulators
- Industry Consolidation
- Technology Advancements
- Increased ADAS Market Need

Government Bodies and Regulators

To achieve increase in safety of travellers, decrease in fuel wastage, and reduce road congestions, government agencies are actively promoting technologies supporting connected cars. Few examples are mentioned below:

- The US Department of Transport (DOT) has mandated all vehicles in the US to be equipped with V2V technology by 2023 in order to reduce collisions. The mandate will be implemented in three phases and will commence in 2021.
- The European Union has mandated all vehicles in the EU to be equipped with the eCall technology from April 2018 onwards. eCall is a technology that automatically dials 112 (emergency number in Europe) in case of a severe accident.
- The National Science and Technology Development Agency (NSTDA) (agency of Government of Thailand) collaborated with the Asian Institute of Technology (AIT) to develop an application – CarTalkWaaS – which would enable exchanging data such as traffic information and news with connected cars.

Source: Frost & Sullivan

4.3 Industry Consortiums are Driving Developments

Term	Near Term	Medium Term	Long Term
Level of Impact	High	High	Medium

- Government Agencies & Regulators
- **Industry Consolidation**
- Technology Advancements
- Increased ADAS Market Needs

Industry Consolidation

- A very high level of integration amongst various industries have been observed in the connected cars industry resulting in increased depth of knowledge related to the technologies associated with connected cars. Also, many industry consortiums have been formed with an intent to develop, test, and promote technologies related to connected cars. This has also resulted in increased awareness for various technologies related to the industry.
- AUDI AG, BMW Group, Daimler AG, Ericsson, Huawei, Intel, Nokia, and Qualcomm Incorporated, announced the formation of the '5G Automotive Association' in September 2016. The goal of this association is to address road safety needs through applications such as intelligent transport system for smart cities, ubiquitous connectivity for the vehicles, and so on.
- Tier I companies such as Aisin, Continental, Delphi, Harman International, Magneti-Marelli, and Visteon have formed the GENIVI Alliance. It is a non-profit organization for developing innovative applications through open software for in-vehicle infotainment (IVI) systems.
- The European Automotive-Telecom Alliance comprises 37 leading automotive companies that have come together to develop solutions related to autonomous driving, road safety, and data management for connected vehicles.

Source: Frost & Sullivan

4.4 High Level of Competition is Accelerating Innovations

Term	Near Term	Medium Term	Long Term
Level of Impact	High	High	High

- Government Agencies & Regulators
- Industry Consolidation
- **Technology Advancements**
- Increased ADAS Market Needs

Technology Advancements

- The connected cars industry is characterized by rapid innovations and advancement of related technologies. This industry is highly competitive because of the involvement of a wide range of stake holders.
- Multiple technologies associated to the connected car industry have facilitated entry of new companies. The high level of market competition has resulted in technology development and application diversification at a reduced cost. The emerging applications has been playing a major role for adoption of connected cars.
- Companies such as Apple and Google have entered the market and are developing self-driven vehicles. While Apple has invested as much as $10 billion for developing machine learning and self-driven technologies, Google has already made its driverless cars available to the public for free rides in Phoenix, Arizona.

Source: Frost & Sullivan

4.5 Need of ADAS Bolstering V2X Development Initiatives

Term	Near-term	Medium term	Long term
Level of Impact	High	High	High

- Government Agencies & Regulators
- Industry Consolidation
- Technology Advancements
- **Increased ADAS Market Needs**

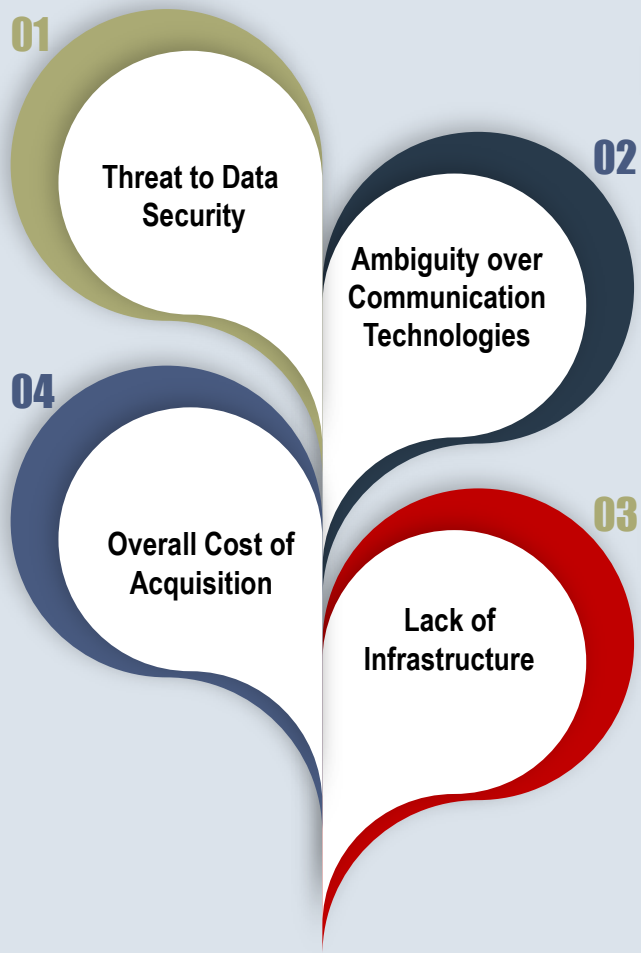
Increased ADAS Market Needs

- ADAS is currently creating a stir in the automotive industry. Automotive OEMs are investing heavily on the development of ADAS solutions for improving safety of the travelers and enhance travel experience.
- Development in V2X compliments ADAS applications. Lane departure systems, blind spot detection, speed detection, direction determination are some of the many applications that will assist drivers. V2X would enable the development of ADAS solutions, which will deliver an autonomous driving experience.
- U-blox, a Swiss-based semiconductor company, has been working on development of V2X transceiver 802.11p modules, which will aid in acceleration of ADAS applications.

Source: Frost & Sullivan

4.6 Data Security, Lack of Infrastructure, Acquisition Cost, and Ambiguity over Communication Technologies are Key Challenges

Connected Cars: Industry Challenges, Global, 2017–2027



Threat to Data Security

Short Term Impact (1–2 Years)	Medium Term Impact (3–4 Years)	Long Term Impact (5-11 Years)
High	High	Medium

Ambiguity over Communication Technologies

Short Term Impact (1–2 Years)	Medium Term Impact (3–4 Years)	Long Term Impact (5-11 Years)
High	Medium	Low

Overall Cost of Acquisition

Short Term Impact (1–2 Years)	Medium Term Impact (3–4 Years)	Long Term Impact (5-11 Years)
High	Medium	Low

Lack of Infrastructure

Short Term Impact (1–2 Years)	Medium Term Impact (3–4 Years)	Long Term Impact (5-11 Years)
High	Medium	Low

Source: Frost & Sullivan

4.7 Threat to Data Security is the Biggest Concern in the V2X Industry

Threat to Data Security

- As more and more cars get connected wirelessly, this technology opens up several gateways for hackers to access and manipulate car data. For example, hacking the accelerator or steering of the vehicle, social networking credentials through infotainment systems, hacking phone and message logs through smart phones.
- In order to ensure data security of vehicles, it must be capable to tackle various remote surface attacks. Also, every car manufacturing company deploys operating system of its choice.
- The number of connected cars is predicted to become 240 million globally and lack of a universal standard for security of connected cars can complicate deploying security features in future .

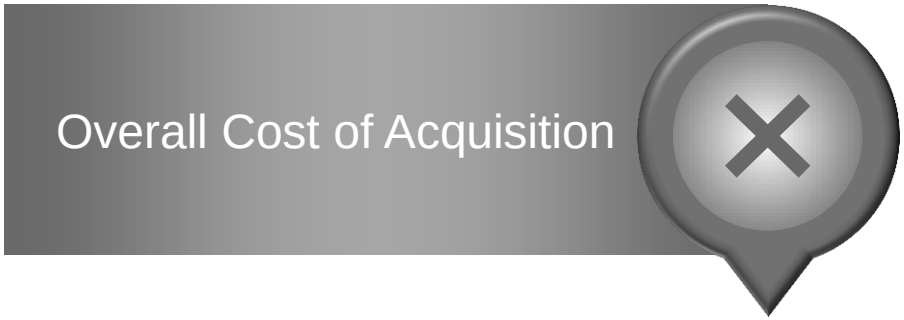
Ambiguity over Communication Technologies

- Currently, there are three proposed protocols for communication between connected cars – DSRC, Cellular, and Hybrid.
- While DSRC is a mandate proposed by the US DOT, the European Union has made its stand clear and taking actions regarding mass deployment of Hybrid communication system.
- Moreover, associations like 5GAA propose cellular communication technology to deploy V2X.
- Industry alliances including key industry participants and national bodies have been formed across various level of stakeholders in the connected car industry to promote various communication technologies.
- The pros and cons of each of the proposed technology have slowed the process of mandating connected car technology.

Source: Frost & Sullivan

4.8 Implementation Cost can hinder Wide scale Adoption

- For successful implementation of V2X technologies, ubiquitous connectivity is a requisite.
- In addition to a sophisticated network infrastructure, the technology also demands upgradation of all roads, roadside units, and overall infrastructure.
- With more cars communicating wirelessly, a lack of appropriate infrastructure would limit the value of services provided by the technology.



- The cost of implementing sophisticated V2X technologies in the car increases the cost of the vehicle.
- In addition, upgradation of cities and spreading awareness amongst first time buyers adds to the overall cost of deploying the technology and acquiring customers.
- In the short term, the cost of acquiring customers can be a major constraint for adoption of this technology in developing APAC countries, but with increase in market competition and the decreasing costs of products, cost of deploying V2X technologies and acquiring customers would not me a major constraint in the long term.

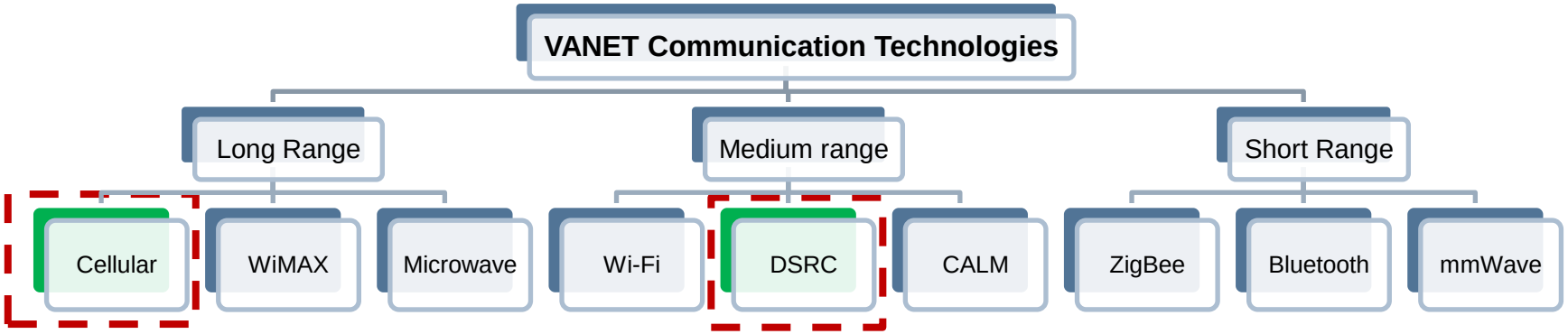
Source: Frost & Sullivan

5.0 Key Technologies Enabling Vehicle-to-everything Communication

5.1 VANET Communication Technologies

- Vehicular ad hoc networks (VANETs) are technologies developed specifically for vehicular communication. It is a class of mobile ad-hoc network (MANET), which plays an important role in the development of intelligent transport systems (ITS).
- Some of the key wireless communication technologies, which have an impact in VANET include cellular systems, WiMAX, Microwave, Wi-Fi, DSRC, ZigBee, Bluetooth, and millimeter (mm)wave communication.
- Various existing VANET communication technologies classified on the basis of range of communication are depicted in the exhibit below. Cellular and DSRC prove to be potential communication technologies enabling connected cars.

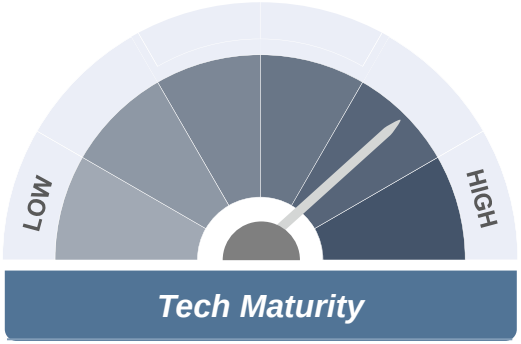
VANET Communication Technologies, Global



Source: Frost & Sullivan

5.2 Significance of DSRC

DSRC (Dedicated short-range communications) is an ad-hoc technology for V2V and V2I applications, standardized on the basis of IEEE802.11p. This technology has been allotted a 70 MHz spectrum in the 5.9 GHz band by North America and Europe, and the 5.8 GHz spectrum in Japan.



Key Recent Updates

- **Smart City Challenge:** In December 2015 U.S. DoT announced Smart City challenge where mid-sized cities across America were asked to adopt intelligent transport system. Seven finalists of the Smart City Challenge in US to add more than 1000 road side units and 13000 vehicles enabling DSRC technology.
- **Latest Trial**: GM successfully demonstrated V2I technology in Michigan through DSRC in June 2017.

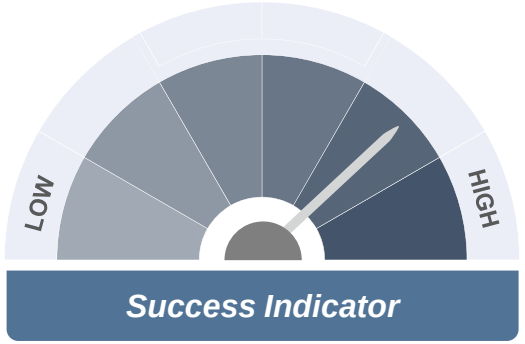
Pros and Cons

PROS:

- DSRC can operate in the absence of network.
- DSRC field trials have been conducted for more than 10 years and hence it's a tested and a proven technology.

CONS:

- DSRC requires visibility and not suitable for multimedia features requiring high bandwidth.
- It lacks extensive network coverage.



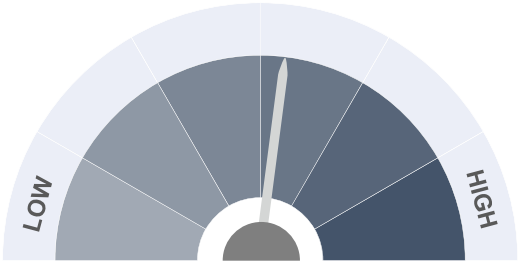
Key Entities to Watch

OEMs:
Ford Motors Co., General Motors Co., Toyota Motors
Semiconductor Companies
NXP Semiconductor (Netherlands), Autotalks (Israel)
Auto & Truck Part Manufacturing Companies:
Cohda Wireless
Industry Consortiums:
Wi-Fi Alliance, Car2Car Communication Consortium

Source: Frost & Sullivan

5.3 Significance of C-V2X

The use cellular technology for connected cars is still in the process of standardization and expected to be regulated with the launch of Release-14 of 3rd Generation Partnership Project (3GPP). Although LTE technology currently leverages V2V and V2I applications for connected cars, wide scale adoption of C-V2X heavily relies on implementation of 5G.



Tech Maturity

Key Recent Updates

- AT&T, Jaguar Land Rover, NTT DoCoMo and Samsung Electronics joined 5GAA.
- Savari Inc., has also joined the board of 5GAA and is the first V2X technology solution provider to join the alliance.

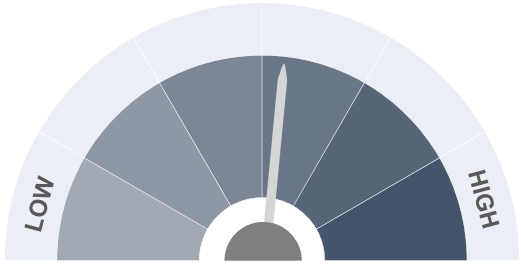
Pros and Cons

PROS:

- Cellular networks support higher speed of data transmission compared to DSRC technology.
- Cellular networks cover a large area and are suitable for long range applications.

CONS:

- There are no dedicated standards as yet (Expected 3GPP Release 14 onwards).
- High communication costs



Success Indicator

Key Entities to Watch

OEMs:

Daimler AG

Semiconductor Companies:

Qualcomm, Samsung Electronics, Intel

Auto & Truck Part Manufacturers:

Harman International, Savari

Industry Consortium:

5G Automotive Association

Source: Frost & Sullivan

5.4 Technology Competence Assessment of DSRC and Cellular Technologies

DSRC (802.11p)	Key Communication Technologies	Cellular (LTE)
DSRC provides medium range connectivity of 300 to 1000 meters.		Cellular communication technology provides long range connectivity of up to 2 kilometers.
It provides ultra low latency of around 200 µs		It provides higher latency than DSRC, around 1.5 – 3.5 seconds
It enables adequate rate for data transmission of up to 27 Mbps required for V2V and V2I applications		It enables a high rate for data transmission - supports U/L up to 75 Mbps and D/L up to 300 Mbps
It is highly suitable for V2V applications and moderately suitable for V2I applications. ***Key proposed applications:*** Collision detection, electronic toll collection, traveler information services		It is more suitable for V2I applications and moderately supports V2V applications. ***Key proposed applications:*** Traffic management systems, multimedia services

Source: Frost & Sullivan

6.0 Cost Analysis of Suitable Vehicle-to-everything Communication Technologies

6.1 Assessment of Cost for Deploying V2V Technologies

V2V,Cost Insights, US, 2020-2058

1

Vehicle Equipment Costs

New vehicles would have V2V units installed, but used cars would need to install additional units (Estimated per vehicle: $329 in 2020, reducing to $186 to $199 in 2058)

2

Fuel Economy Impact

V2V devices would make the vehicles heavy resulting in increased fuel consumption, adding to the overall cost. (Estimated per vehicle: $9 to $18)

3

Security Credential Costs

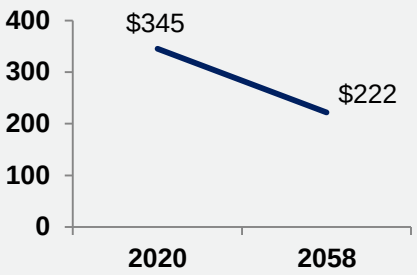
Establishing secured communication links would require installation of additional roadside units (RSUs) (Estimated per vehicle: $3.1)

4

Communication Costs

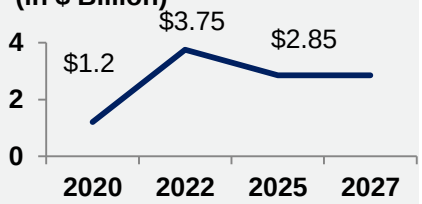
Security credential management systems (SCMS) unit must be installed to authenticate the data received by vehicles. (Estimated per vehicle: $8.3 to $8.5)

Average Increased Cost per Vehicle (in $)



The average cost per vehicle is forecasted to increase by approximately $345 in 2020 compared to current cost and decrease to $222 in 2058.

Total Deployment Cost (in $ Billion)



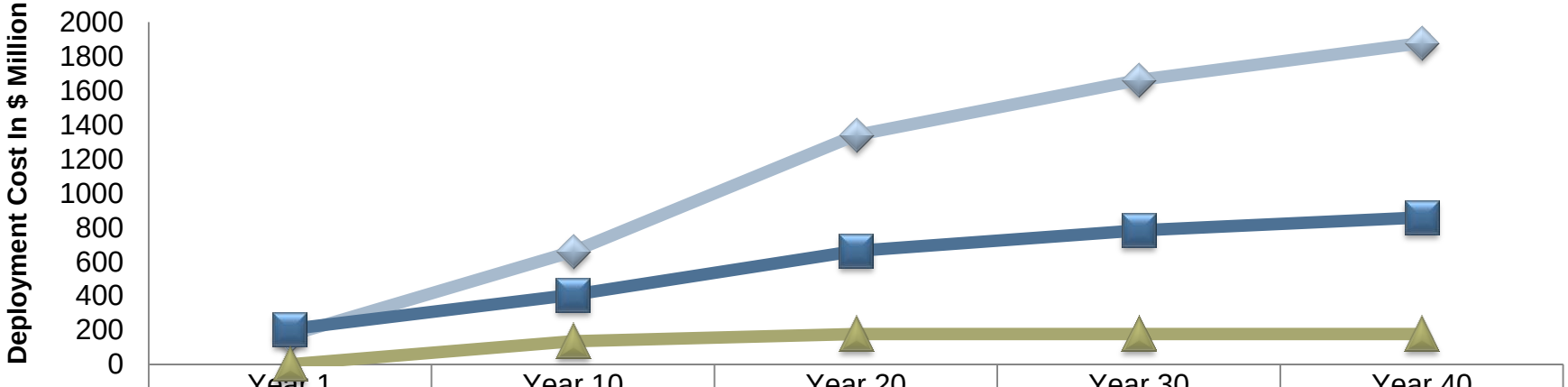
The average total cost of deploying connected car technology is projected to rise from approximately $1.2 billion to $3.75 billion in 2022 and then gradually become an average annual cost of $2.85 billion.

Note: The above estimation could vary, depending on the speed of implementation of technology.

Source: US Department of Transportation's National Highway Traffic Safety Administration, Frost & Sullivan Analysis

6.2 Overall Cost of Deploying Connected Cars is Low for DSRC

V2V, Total Estimated Cost – Cellular, Hybrid, and DSRC, USA, 2020-2060



	Year 1	Year 10	Year 20	Year 30	Year 40
Cellular	171.592	659.679	1339.399	1661.884	1876.521
Hybrid	205.91	406.205	663.61	782.595	858.907
DSRC	0	135.137	177.681	177.681	177.681

Analyst Point of View:

- The above estimation includes cost of road side units, on-board equipments, and cellular data (Details discussed in the following slide)
- The cost of OBU (outside broadcast unit) is highest for Hybrid, since it needs an additional module to support both Cellular and Wi-Fi networks.
- The cost of cellular data is highest for Cellular technology, followed by Hybrid and DSRC (nil).

Source: US Department of Transportation's National Highway Traffic Safety Administration, Frost & Sullivan Analysis

6.3 Cost Assumptions and Estimation Explanation of Cellular, DSRC, and Hybrid Communication Technologies

V2V, Cost Assumptions and Estimation, US, 2020-2060

Communication Technology	Cellular		DSRC		Hybrid	
Year	Year 1	Year 40	Year 1	Year 40	Year 1	Year 40
Cost of one OBU (Outside Broadcast Unit)	$171.5	$269.3	0	0	$205.9	$323.1
Cost of one RSU (Roadside Unit)	0	0	0	$177.6	0	0
Communication Cost	0	$1607.2	0	0	0	$535.7

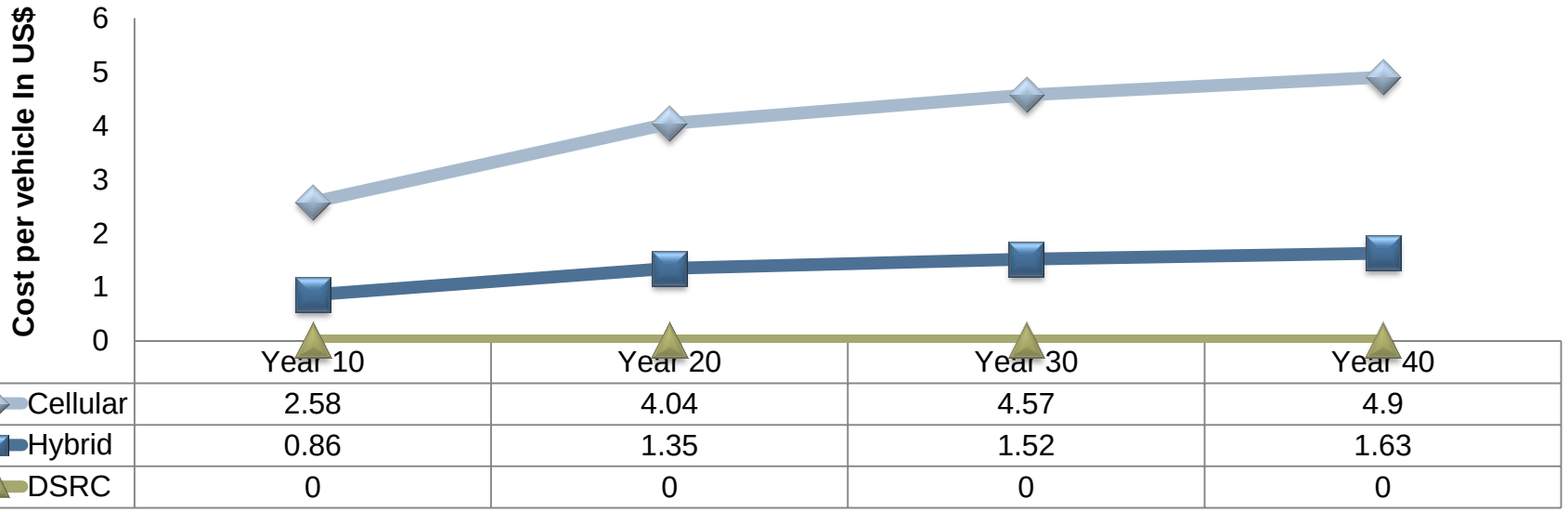
Cost Assumptions:

- **Scenario – Aggressive implementation of technology**
  - In 2020, there will be implementation of 35%
  - In 2021, it will be 70%
  - In 2022 , there will be100% implementation
- **Cellular data price** – $4.00/GB
- **No. of Nationwide RSUs (US)** – 19750 units
- **Lifetime of one RSU –** 15 years
- **Cost of OBU**
  - Cost of one OBU for Cellular communication – $10
  - Cost of one OBU for Hybrid – $12
- **Cost of RSU**
  - One time cost of one RSU – $8839
  - Replacement cost of one RSU – $22719

Source: US Department of Transportation's National Highway Traffic Safety Administration, Frost & Sullivan Analysis

6.4 Communication Data Costs is Observed to be Lowest for DSRC

V2V, Communication Data Cost Estimate per Vehicle, US, 2020-2060



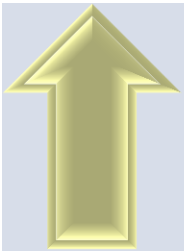
	Year 10	Year 20	Year 30	Year 40
Cellular	2.58	4.04	4.57	4.9
Hybrid	0.86	1.35	1.52	1.63
DSRC	0	0	0	0

Analyst Point of View

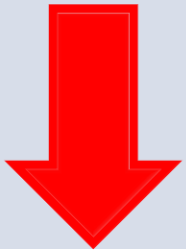
- The communication cost per vehicle increases year-on-year as the number of vehicles that must be communicated with increases significantly. Also, with the advancement in connected car technology, more applications will be discovered, adding to the exchange of data between connected vehicles.
- DSRC requires no Wi-Fi or cellular data. The only cost involved is installation cost and maintenance cost of RSUs.
- Ease of implementation (no need for a new business model), readiness of technology, and data security standards makes DSRC a preferred technology for enabling safety applications through connected cars.

Source: US Department of Transportation's National Highway Traffic Safety Administration, Frost & Sullivan Analysis

6.5 Analyst Point of View – Communication Costs



Benefits of DSRC outweigh cellular communication



Cost associated with the adoption of cellular communication can hinder its implementation

- DSRC is defined by the IEEE 802.11p standard. The technology is an established and reliable platform for short range communication (up to 300 meters). The system transmits basic safety messages (BSMs) such as vehicle location, speed, direction, braking information, and other details. With the system being updated and date being transmitted every 10 seconds, the solution seems to be the ideal choice of communication system for vehicular communication.
- Cellular vehicle to everything (C-V2X) on the other hand utilizes existing 4G cellular standards (Long-Term Evolution [LTE]). Unlike the proven technology such as DSRC, utilization of cellular standards for V2V and V2X communication would require service agreements from carriers. Also, the cost associated with the utilization of cellular communication for vehicular communication is very high.
- From the above cost analysis, it can be noted that the cost associated with the implementation of DSRC, the IEEE 802.11p standard for V2X communication is cost effective compared to cellular communication technologies.
- Although C-V2X using LTE is also an established communication technology currently, it is unclear of its prospects in vehicular communication. With 5G poised to be commercially available in the medium term, reliance of cellular communication can hinder the commercialization prospects of V2X communication.
- Based on cost analysis and the above mentioned facts, *Frost & Sullivan* believes that DSRC will be the suitable communication technology for V2X communication.

Source: Frost & Sullivan

7.0 Industry Initiatives

7.1 Key Global Industry Initiatives by Automotive OEMs

In 2017, Volkswagen a German based global automotive OEM, announced the availability of v2v communication in their product portfolio by 2019. The company is expected to utilize the IEEE 802.11p public wireless LAN (pWLAN) DSRC wireless standard for the cars to communicate with other cars and infrastructure.

Groupe Renault, a French based automotive OEM is currently working with Sanef, a French motorway infrastructure solutions provider for the development of communications between autonomous vehicles and motorway infrastructure such as tolls, work zone and many others.

Land Rover is currently working on the development of “Autonomous Urban Drive system”, which would offer SAE Level 4 (U.S. Department of Transportation (DoT) standards for high automation) in its products. Cars implementing this technology can be expected to be commercially available in the long term and can be expected to communicate with cars and infrastructure around it, leading to the development of highly automated vehicles (HAVs).

Cadillac, a division of US based General Motors is expected to offer V2X communication functionality in its upcoming version of Cadillac-CTS sedan. The company has entered into a partnership with Cohda Wireless, an Australian based V2X technology provider is involved in integration of the technology in their product which is expected to be commercially available towards the end of 2017. The company has also entered into a partnership with NXP Semiconductors for the development of ROADLINKS for V2X communication, Delphi Automotive for supplying antenna modules and Security Innovation for providing data security.

Source: Frost & Sullivan

7.2 Automotive OEMs to offer V2X for improving safety

Toyota

Driving Safety Support System (DSSS)
Toyota is one of the forerunners in the automotive space to implement V2V communication in its product portfolio. The company has invested heavily on the development of cooperative Intelligent Transportation Systems (C-ITS). In 2016, the company had offered DSSS capability in its products- Prius, Crown Majesta, Crown Royal and Crown Athlete. It is also one of the forerunners in the market to offer V2X solutions in the 760 MHz band as it believes it to be suitable for V2V and V2I applications.

Daimler

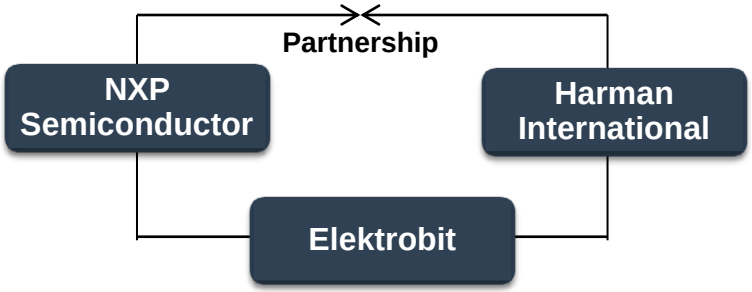
Car-to-X communication
In 2017, Daimler took a step towards autonomous driving by integrating Mercedes E-class with Car-to-X communication. The technology informs the driver about any hazardous conditions on the road such as weather, accidents and others. It aids in increasing safety, enhancing efficiency and reducing stress associated with driving. The communication in this system is enabled through onboard cellular connection.

Honda

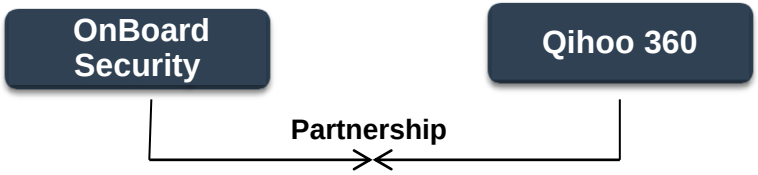
Connected Vehicle Safety
Honda, a Japan based global automotive OEM has been one of the pioneers in the R&D and testing of technologies enabling connectivity in the automotive sector. The company has recently demonstrated advanced Vehicle-to-Pedestrian (V2P) and Vehicle-to-Motorcycle (V2M) safety technologies with communications enabled through Dedicated Short Range Communications (DSRC) technology. The solution is a part of the comprehensive connected vehicle safety program of Honda which aims in reducing collision between vehicles and pedestrians greatly.

Source: Frost & Sullivan

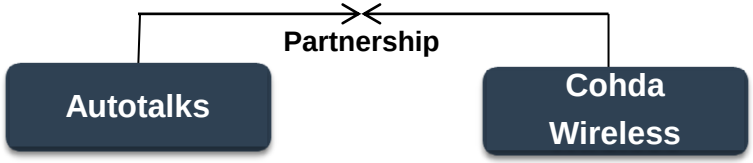
7.3 Recent Industry Partnerships and Collaborations



In June 2017, NXP Semiconductor, a global infrastructure and secure communications provider announced its collaboration with Elektrobit, a Finland based wireless communication technology company for the development of a platform suitable for autonomous and connected car. The platform is intended to be developed in partnership with Harman International in order to speed up the time of commercialization of Harman's connected car solutions.



OnBoard Security, Inc., a subsidiary of Security Innovation is a US based security provider for V2V communication. In 2017, OnBoard Security entered into a partnership with Qihoo 360, a Chinese based internet platform and cyber security company for the research and development of security solutions suitable for communication in connected and autonomous cars. This partnership is expected to greatly advance development and adoption of connected cars in China.



In 2016, Autotalks, a Israel based V2X communication processor developer entered into a partnership with Cohda Wireless, an Australia based company developing software solution for Connected Autonomous Vehicle (CAV) market. The partnership is intended in creating interoperability between the two platforms (developed by respective companies), which can prove to be critical for V2X communication.

Source: Frost & Sullivan

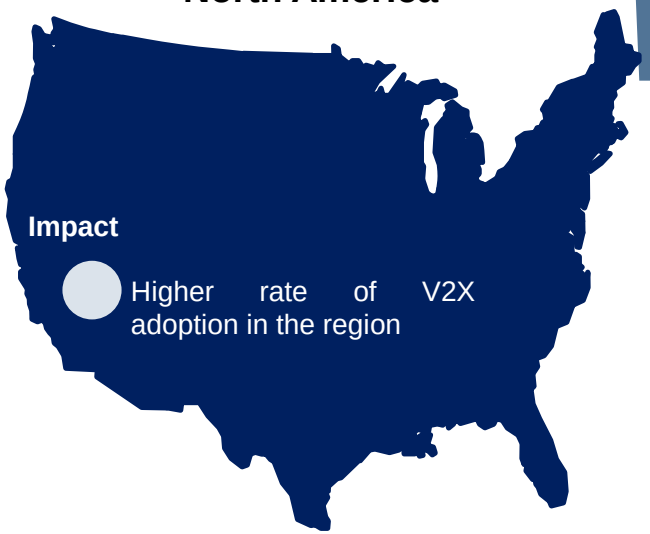
8.0 Region-wise Impact Assessment

8.1 Government initiatives encourage V2X adoption in the region

Government Initiatives Push Development

Collaboration between Automakers and OEMs

North America



- North American region is witnessing increased activity in connected and autonomous vehicle development. USA leads the region with the number of innovations complimenting the advancement and adoption of V2X communication.
- U.S. Department of Transportation released a Notice of Proposed Rulemaking, mandating the inclusion of car-to-car communication in the entire U.S. light vehicle fleet using DSRC (IEEE 802.11p standard). The initiative has been taken by the US government to reduce accidents and collision, thereby preventing hundreds of crashes which are witnessed currently.
- U.S DOT's Federal Highway Administration is expected to provide a set of guidelines for Vehicle-to-Infrastructure (V2I) communications. These guidelines can be expected to support automotive OEMs and motorway infrastructure developers to integrates technologies which would allow vehicles to communicate with infrastructure such as traffic lights and signals.
- The US Federal Communications Commission has currently allocated 75 MHz of spectrum and for communication in Intelligent Transportation Systems.
- Various global automotive OEMs are working heavily with semiconductor companies, software providers, communication companies and hardware providers for the development of a suitable V2X solution which can be adopted in this region.

Source: Frost & Sullivan

8.2 Consortiums and partnerships spur technology advancement

European Scenario

Impact Indicator

Higher rate of V2X adoption in the region

- European Region is an attractive market for V2X communications due to the presence of various global automotive OEMs who have originated from this region. IAA (International Automobile Exhibition) Frankfurt Motor Show witnesses a number of developments made by each company every year.
- European region has been allocated with a ETSI ITS-G5 standard for Intelligent Transport Systems operating in the 5 GHz frequency band. Research on the capability of utilizing 5G for V2X communication is also high in this region. In 2017, 5G Automotive Association (5GAA) and the European Automotive and Telecom Alliance (EATA) signed a MOU (Memorandum of Understanding) for the advancement of Cellular-V2X (C-V2X).
- The region witnesses various industrial consortiums, research initiatives and collaborative testing for addressing the challenges associated with V2X communication. CAR 2 CAR Communication Consortium, comprising multiple automotive OEMs and technology developers keenly focuses on the development of Cooperative Intelligent Transport Systems and Services (C-ITS) and to implement them on European roads. The consortium also plays a vital role in the allocation of 5.9 GHz spectrum, commonly referred as ITS-G5 communication for a safe V2V and V2I communication.
- Germany, Austria, France, the Netherlands and Denmark, can be expected to be the early adopters of V2X communication. Government agencies across the region are supporting the development of the technology to reduce collision based accidents. They are investing heavily on the development of infrastructure which would enable suitable V2X communication in the future.

Source: Frost & Sullivan

8.3 Telecommunication providers show keen interest to enter V2X communication market

Asia Pacific Scenario

Impact Indicator

Higher rate of V2X adoption in the region

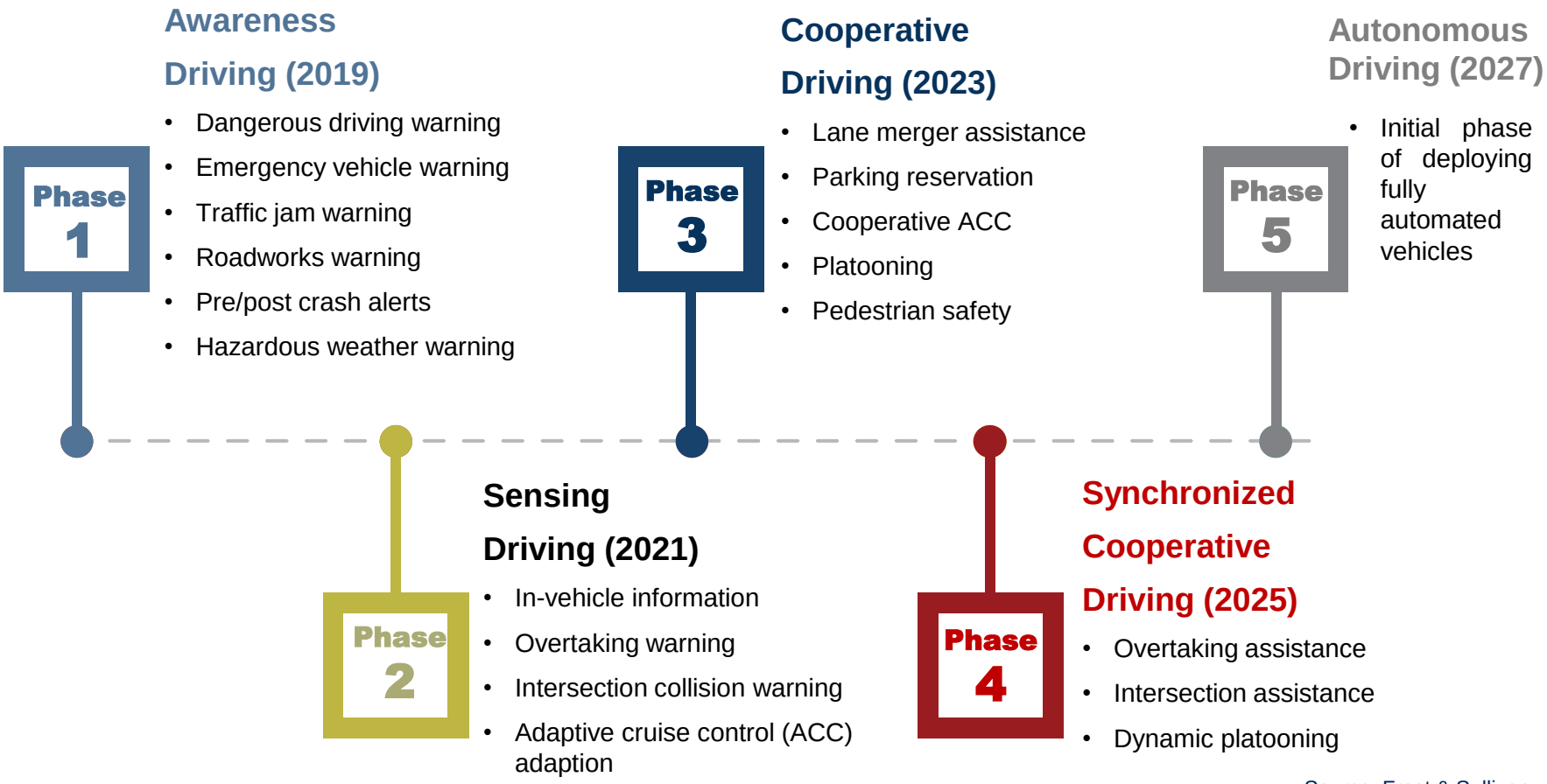
- Automotive OEMs and telecommunication technology providers are the key participants in this region working on the development of V2X communication. China and Japan are expected to lead the region in the technology development space.
- Honda and Toyota, Japan based global automotive OEMs are some of the forerunners in the V2X space in this region who have been investing heavily and working on the development of V2X solutions.
- A number of consortiums and partnerships have been initiated in this region for testing the capability of cellular systems in V2X communication. In 2017, Hong Kong Applied Science and Technology Research Institute (ASTRI), telecom operator Hong Kong Telecommunications Limited (HKT), Huawei and Qualcomm formed a consortium for the development of smart mobility systems suitable for c-V2X and improving Hong Kong's transportation sector.
- In South Korea, SK Telecom, a South Korea based wireless telecommunications provider has successfully tested the capability of 5G network in connected cars by working in collaboration with Ericson and BMW, Korea.
- In Singapore, Nanyang Technological University (NTU) in partnership with NXP Semiconductors launched a Smart Mobility Consortium which aims in testing and developing smart solutions suitable for connected and autonomous vehicles.
- Telstra Corporation Ltd., an Australian telecommunications provider collaborated with Cohda Wireless, a V2X technology provider for testing the capability of V2X communication using its LTE (Long Term Evolution) network. The test confirmed the capability and suitability of LTE for V2X communication (LTE-V2X).

Source: Frost & Sullivan

9.0 Applications Roadmap

9.1 Connected Car Applications Roadmap

V2X communication is an emerging area that can transform the automotive and transportation sectors in the future. Technologies, such as wireless communication, advanced imaging, virtual reality, augmented reality, GPS (global positioning system), and many other sensor technologies are integrated to develop advanced vehicular communication solutions. The following are some of the applications which are possible using V2V and V2X communication (These applications are explained in the next slide).



Source: Frost & Sullivan

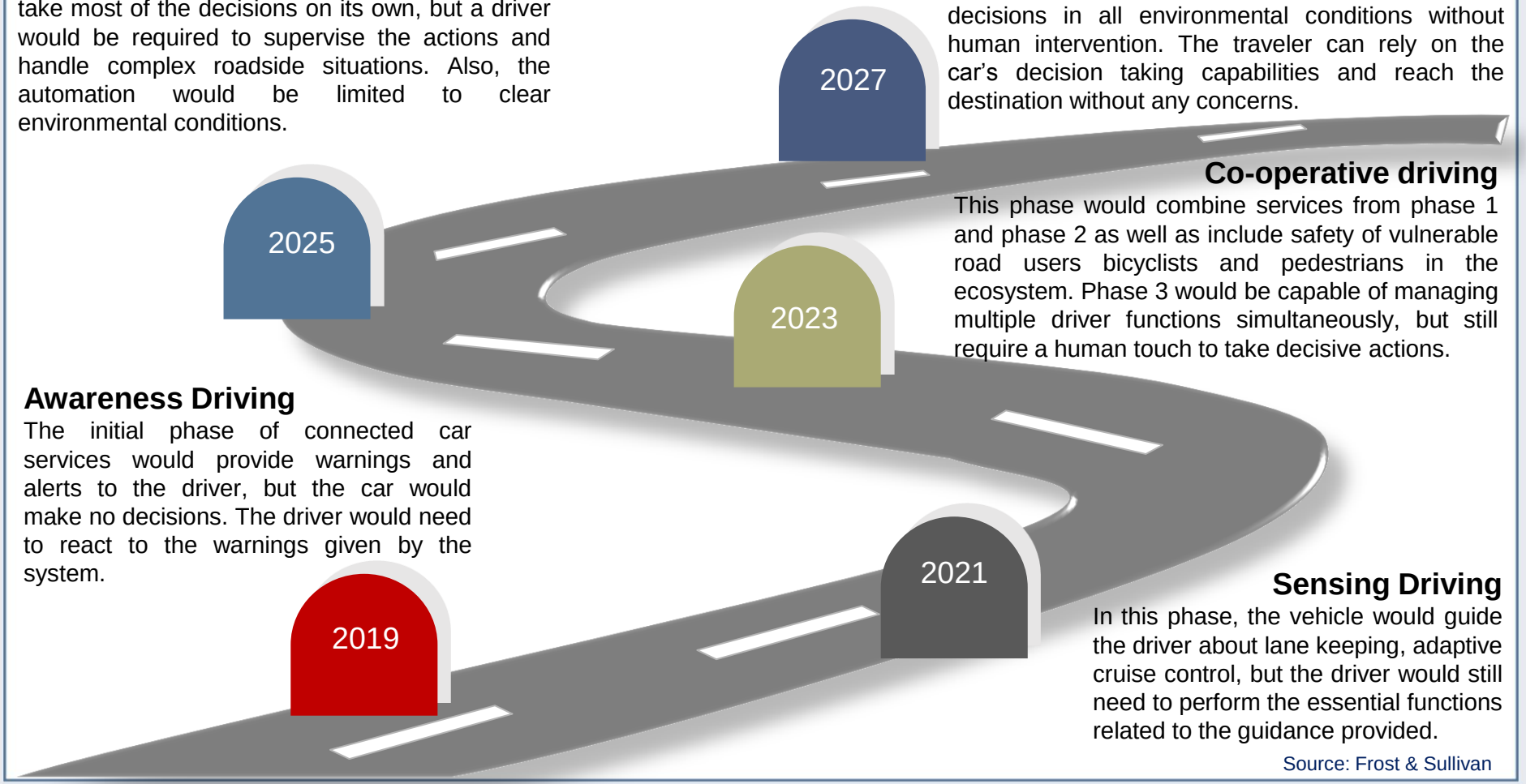
9.2 Future trends are geared toward Autonomous drivability

Synchronised Co-operative driving

Phase 4 of connected car services include semi-autonomous driving. The vehicle would be able to take most of the decisions on its own, but a driver would be required to supervise the actions and handle complex roadside situations. Also, the automation would be limited to clear environmental conditions.

Autonomous Driving

The final stage of connected cars envisioned is a fully autonomous vehicle, which would be capable of making complex decisions and taking appropriate decisions in all environmental conditions without human intervention. The traveler can rely on the car's decision taking capabilities and reach the destination without any concerns.



Co-operative driving

This phase would combine services from phase 1 and phase 2 as well as include safety of vulnerable road users bicyclists and pedestrians in the ecosystem. Phase 3 would be capable of managing multiple driver functions simultaneously, but still require a human touch to take decisive actions.

Awareness Driving

The initial phase of connected car services would provide warnings and alerts to the driver, but the car would make no decisions. The driver would need to react to the warnings given by the system.

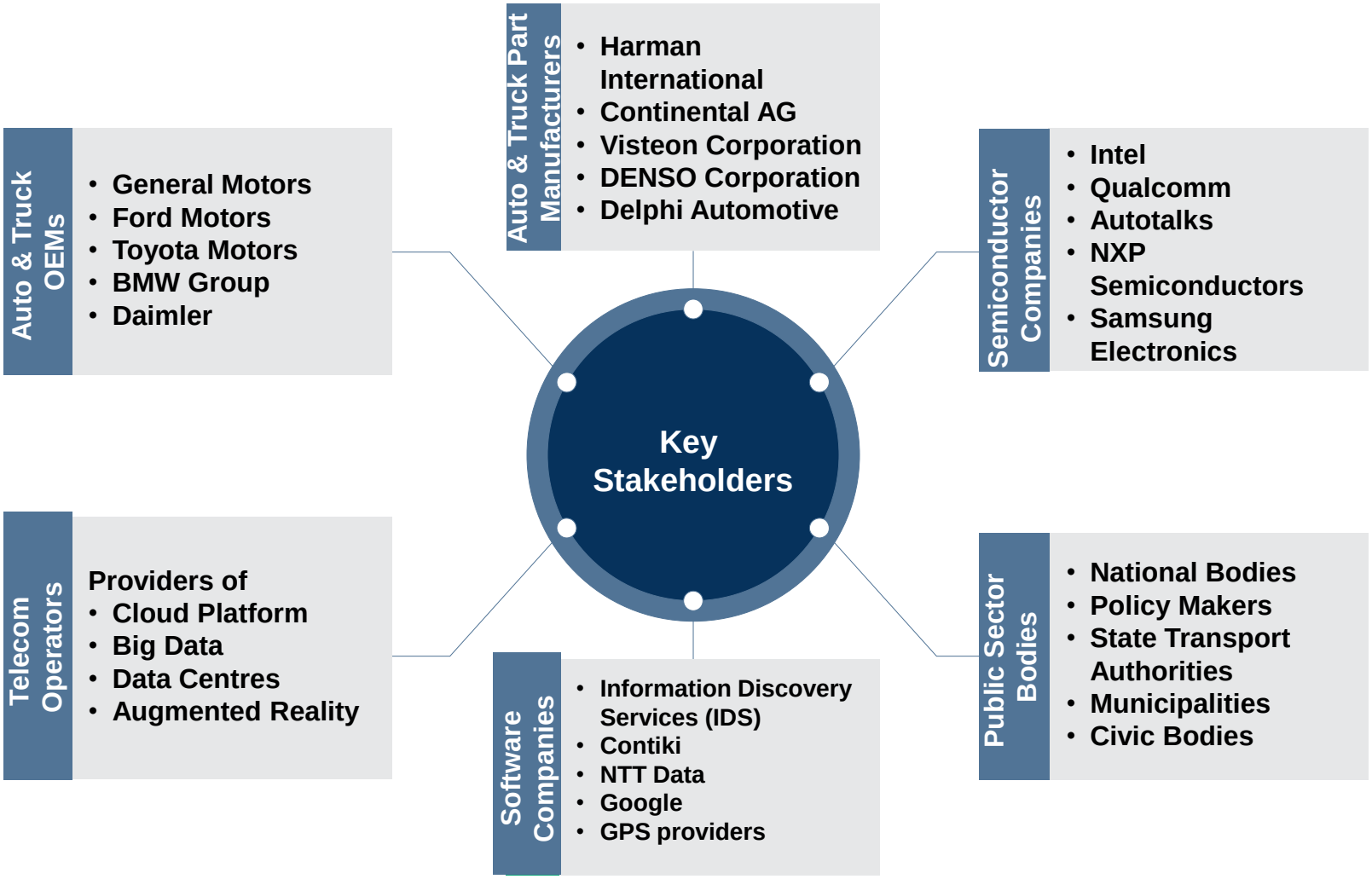
Sensing Driving

In this phase, the vehicle would guide the driver about lane keeping, adaptive cruise control, but the driver would still need to perform the essential functions related to the guidance provided.

Source: Frost & Sullivan

10.0 Strategic Moves of Stakeholders

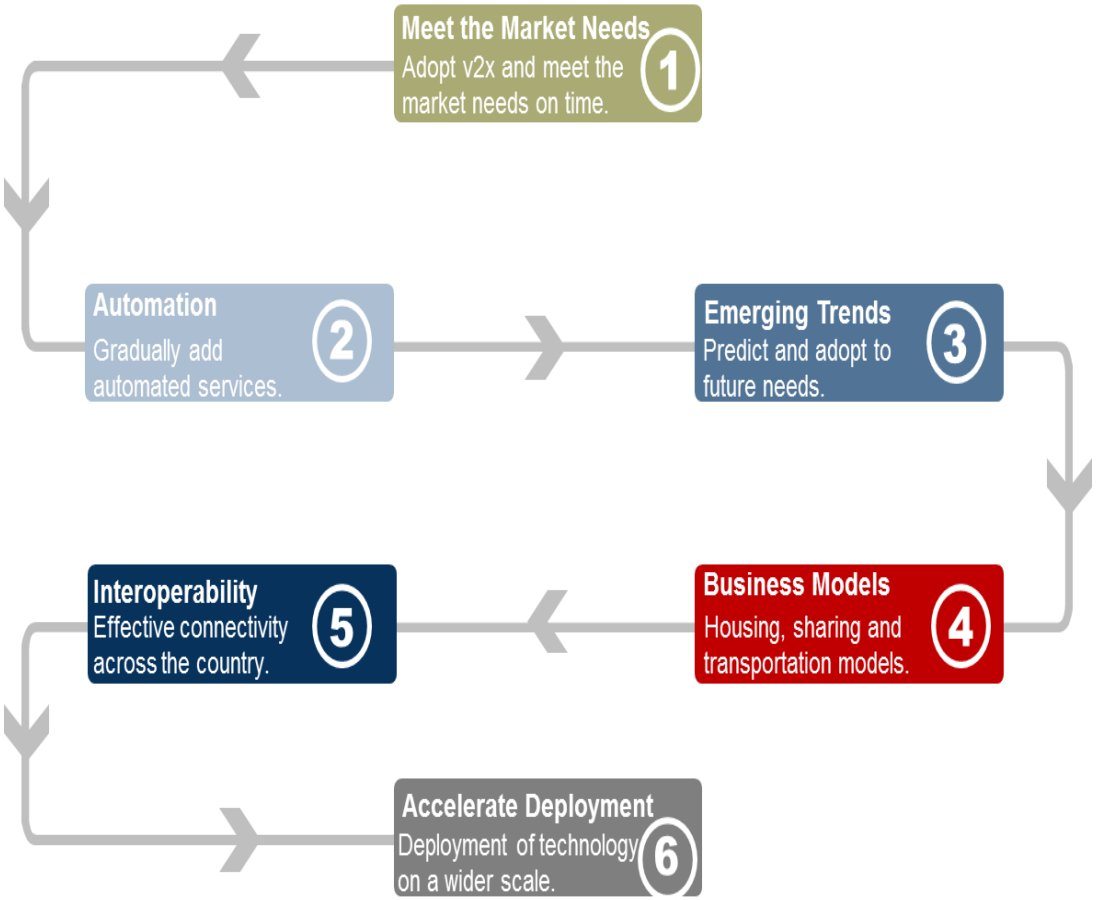
10.1 Key Stakeholders Associated with V2X Communication



Source: Frost & Sullivan

10.2 Strategies to be Adopted by V2X Stakeholders

Strategic pathway to be chosen by V2X stakeholders

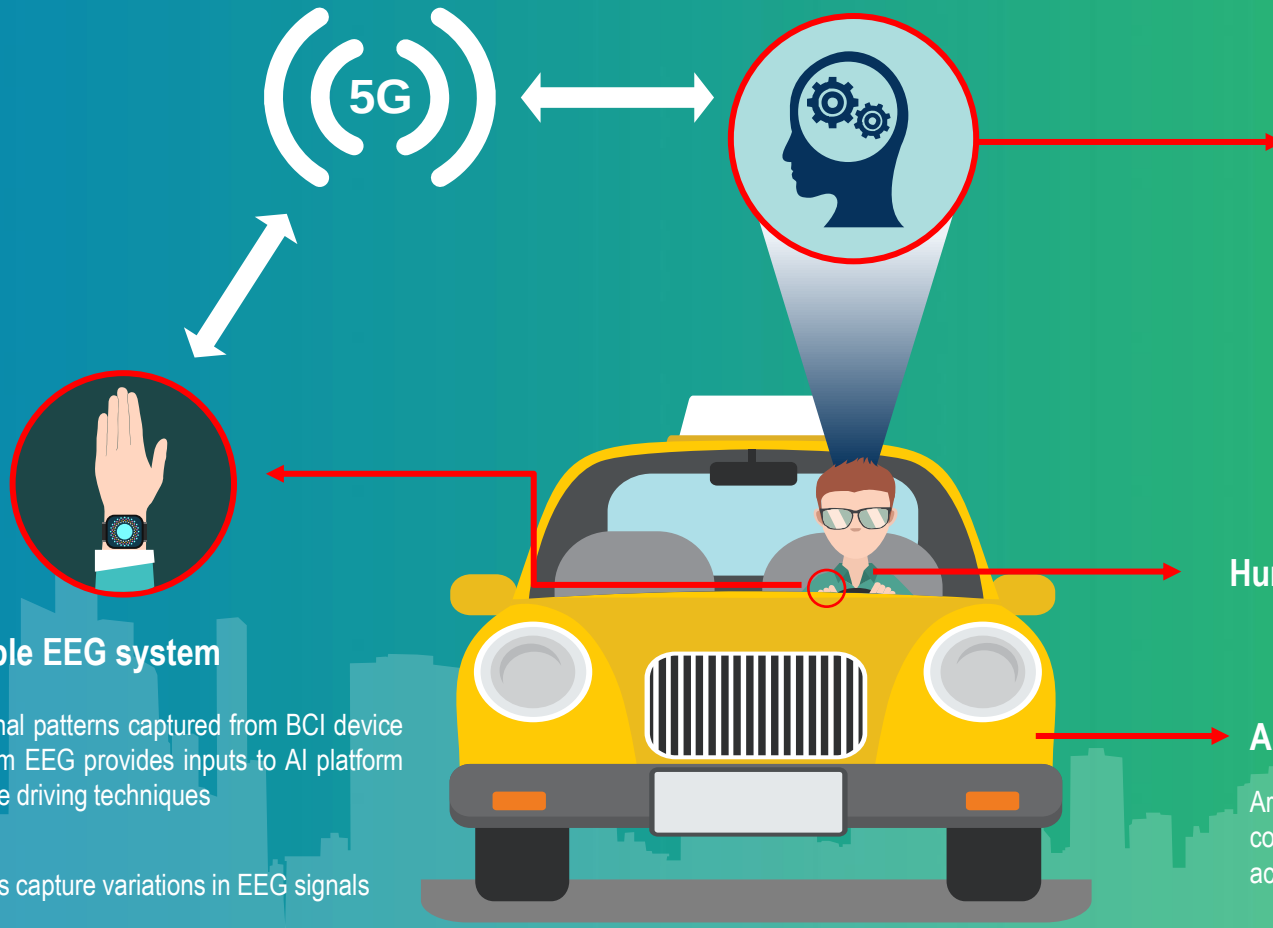


- ✓ The key for any stakeholder associated with the V2X industry is to assess the market needs and adopt the suitable technology for communication. Partnerships between various stakeholders will accelerate the deployment of connected car technologies.
- ✓ International partnerships between stakeholders will help implement connected car technologies more efficiently by leveraging global best practices strategies.
- ✓ A National standard for deployment of connected car technologies must be proposed globally across various countries to ensure nationwide interoperability of vehicles.
- ✓ Developing countries should organize seminars and workshops related to connected car technologies for creating awareness as well as to implement the technology faster.

Source: Frost & Sullivan

11.0 Growth Opportunities

11.1 Convergence Scenario: Autonomous Drive Correction



Brain Computer Interface

Brain waves converted into electrical signals

Human Driver

Autonomous Vehicle

Artificial Intelligence constantly feeds corrective data to the car that improves accuracy of decision making

Wearable EEG system

Brain signal patterns captured from BCI device in the form EEG provides inputs to AI platform to improve driving techniques

Wearables capture variations in EEG signals

- *New possibilities in developing AI systems capable of reading BCI signals will enable autonomous vehicles to learn driving patterns that are very similar to human driving techniques.*
- *Probability of traffic- rule violations and accidents can be reduced by allowing real-time touchless transfer of human intelligence.*

Source: Frost & Sullivan

11.2 Growth Opportunities for Stakeholders

Connected car technology has a very diversified range of stakeholders including OEMs, OEM part manufacturers, semiconductor companies, telecommunication operators, national transport authorities, and local municipality agencies. Connected car technologies require heavy capital investment, awareness, as well as specialization. Industry consolidation can increase cost to benefit ratio.

INDUSTRY CONSOLIDATION

RAPID INNOVATIONS

Due to a wide portfolio of stakeholders, the connected car industry is characterized by rapid innovations within its wide ecosystem. This includes innovations from OEMs as well as startups who aim to gain the market share with their specialized products. University projects related to the connected cars industry can capitalize opportunities from attractiveness of the concept.

Source: Frost & Sullivan

11.3 V2X leads to new business models and strategic partnerships

TESTBEDS

To test the impact and significance of connected car technology, national transport authorities have collaborated with other stakeholders. Smart cities provide ideal testbeds for testing this technology. While smart city challenges are already conducted in developed countries to test smart cars, smart city challenges are expected to be encourage development of connected technologies in developing countries as well.

NEW BUSINESS MODELS

While implementation of DSRC would not require a new business model in near term, the success of cellular V2X would rely heavily on new business models. New business models could include service-based model (customer is charged on the basis of services the vehicle is subscribed to) or transaction-based model (a fixed amount charged to the customer depending on the distance covered by the connected vehicle to complete a trip).

MERGERS & ACQUISITION

Connected car technology is believed to be a first step toward autonomous driving, which would require high R&D and capital investments. Mergers and acquisitions (M&A) would speed up commercialization and wide-scale adoption. A key recent one is Samsung Electronics acquisition of Harman International for $8 billion.

Source: Frost & Sullivan

11.4 Key Strategic Questions from CEO's Perspective

What are the key critical success factors for adoption of V2X?

- V2X communication is expected to complement ADAS in automotive by improving safety. DSRC mandate made in the US can be expected to drive technology adoption.
- Cellular communication providers are actively working on the development of C-V2X, posing as a threat to DSRC. This could expedite developments and commercialization of DSRC to capture the market before commercialization of C-V2X.
- Partnerships, consortiums and collaborations between automotive OEMs and semiconductor companies encourage technology development.

Why DSRC is significant for V2X communication?

- DSRC, which is based on IEEE 802.11p wireless standard has been considered as a standard solution for V2X communication and extensively tested by various automotive OEMs.
- The benefits of DSRC for V2X communication has been proven unlike the competing technologies.
- Cellular technologies on the other hand are not available and are not proven to suffice the requirement of V2X communication.
- Relying on a communication technology which is not commercially available (5G) and not tested will in-turn delay the implementation of V2X.

How can V2X benefit the end-user?

- As years go by, the mortality rate due to road accidents have been increasing. With most of the accidents occurring due to human error, it is imperative for automotive OEMs to offer a solution which would reduce accidents. V2X would aim in reducing of deaths by improving traffic safety.
- Apart from traffic safety, it assists in optimizing traffic flow and reduce congestion. Data collected from connected cars and infrastructure can be used to get desirable output from data management systems.
- V2X assists in reducing the impact of transportation on the environment. Platooning, which will be enabled by V2X can be expected to reduce carbon dioxide emission as autonomous vehicles can be expected to follow each other in free flowing roads.
- It enhances convenience to the driver who is informed about the road conditions prior thereby offering a hassle free driving.

Source: Frost & Sullivan

12.0 Industry Contacts

12.1 Industry Contacts

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Source: Frost & Sullivan

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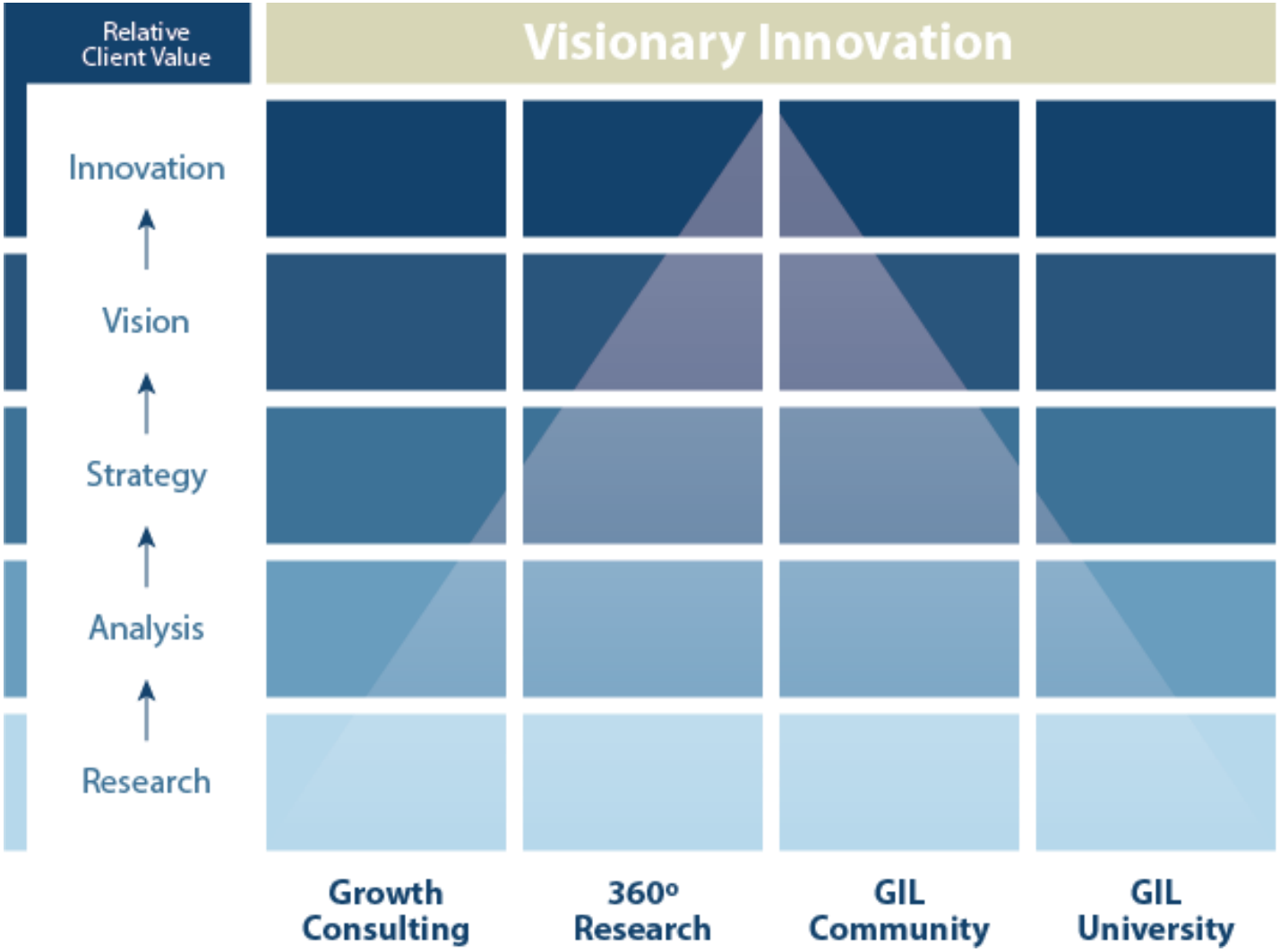
13.0 The Frost & Sullivan Story

The Journey to Visionary Innovation

13.1 The Frost & Sullivan Story

13.2 Value Proposition: Future of Your Company & Career

Our 4 Services Drive Each Level of Relative Client Value



13.3 Global Perspective

40+ Offices Monitoring for Opportunities and Challenges

13.4 Industry Convergence

Comprehensive Industry Coverage Sparks Innovation Opportunities

Aerospace & Defense

Measurement & Instrumentation

Consumer Technologies

Information & Communication Technologies

Automotive Transportation & Logistics

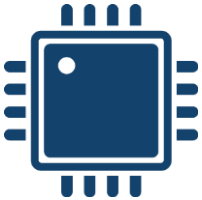
Energy & Power Systems

Environment & Building Technologies

Healthcare

Minerals & Mining

Chemicals, Materials & Food



Electronics & Security

Industrial Automation & Process Control

13.5 360º Research Perspective

Integration of 7 Research Methodologies Provides Visionary Perspective

13.6 Implementation Excellence

Leveraging Career Best Practices to Maximize Impact

13.7 Our Blue Ocean Strategy

Collaboration, Research and Vision Sparks Innovation